Combined heat and power

A real alternative when carefully implemented

Aviel Verbruggen

During the remainder of 1992, a series of papers regarding combined heat and power (CHP) will be published in Energy Policy. *In this article the guest editor highlights some aspects of this many sided and complex technology. Starting from the thermodynamic basics, he considers the main characteristics of jointly generated heat and power outputs. After an overview of the technologies the very different nature of independent versus utility CHP is discussed. The factors determining the economic feasibility are listed with an emphasis on the performance of energy markets linked to CHP. This naturally leads to policy questions. The future of CHP seems less dependent on thermodynamic certainties than on institutional and policy decision making.*

Keywords: CHP; Energy markets; Energy policy

Combined heat and power (CHP) or cogeneration refers to the joint production of electric power and useful thermal energy, such as low temperature heat or steam, through a sequential use of the prime mover energy. Because of physical laws, power generation based on fossil fuels wastes about 50% of the primary energy in cooling water at ambient temperatures. Avoiding these massive losses requires raising the temperature of the rejected heat flows and bringing them to an end-user.

The principles of power generation and, therefore, of CHP have been well known since Carnot ie before electricity generation and supply became an industry. The physical laws were well understood and the technologies were available. Yet the worldwide development of CHP has not kept pace with the growth of the energy business in general and with the growth of electricity generation or steam raising industries in particular. CHP history is one of ups and downs. In some countries CHP has been an issue while in others it has gone unnoticed and in some countries CHP has been embraced while in others it has been rejected.

The availability of the technology, combined with its very unequal implementation, shows that CHP is not a technical issue but one of economics and energy policy. CHP is an important subject and this series will, we hope, strengthen our understanding of the relevant factors, opportunities, and challenges governing CHP development.

IT ALL STARTS WITH THERMODYNAMICS

Good textbooks about thermodynamics[1] teach us that there is but one phenomenon called energy, and that there are but two ways of transferring energy: work (power) and heat. Energy is converted from one form into another in order to be useful for human purposes. In a modern industrial society, there are a variety of conversion processes each one requiring particular types of energy as the prime mover and each one involving particular quantitative and qualitative losses.

From a thermodynamic point of view, work (power) is the noble or high quality transfer of energy, and heat is the less valuable one, its value decreasing with lower temperatures of the available heat source. Thermodynamic laws span the boundaries of the technological energy processes, being in turn the limits of economic feasibilities.

CHP is at the heart of energy production, dealing as it does with power and heat. Power is the high quality output of a CHP process, being convertible to all other forms of energy and, therefore, broadly useful in both a technical and economic way. The

Aviel Verbruggen is Associate Professor at the University of Antwerp, UFSIA, Prinsstraat 13, B-2000 Antwerp, Belgium. The author thanks the EEC Commission, DG 17, for supporting research in cogeneration.

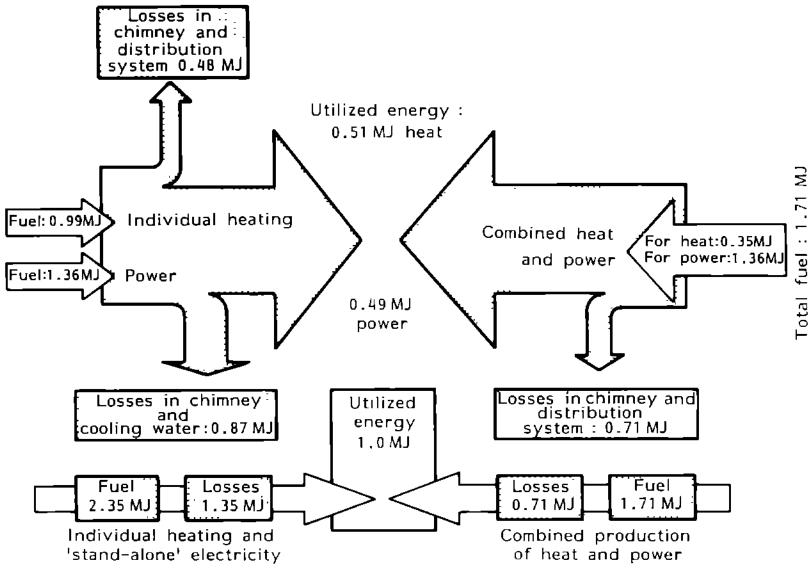

Figure 1. Energy flow diagram for individual production of heat and power compared to combined heat and power production (oil based).

Source: World Energy Council, *District Heating/Combined Heat and Power. Decisive factors for a Successful Use – as Learnt from Experience*, June 1991.

quality and usefulness of the other output, heat, depends on the heat temperature level: at high temperatures it is still convertible to drive power (eg as process steam) but at ambient temperatures heat has lost its technical usefulness and also its economic value. Heat at ambient temperatures is a free good and its price will be zero forever.

If the very different nature of both CHP outputs – power and heat – is not considered continuously, the efficiency numbers can be misleading. Yet the efficiency of CHP is impressive as shown in Figure 1. To meet a given 1.0 MJ end-use of heat and power, 'separate' generation requires 2.35 MJ primary fuel compared to 1.71 MJ in the CHP solution. CHP savings amount to 0.64 MJ, ie 27% of 'separate' primary energy consumption.

TWIN PRODUCTS OF A DIFFERENT KIND

Generally CHP plants face fluctuating loads of heat and electricity while they deliver power and heat in a joint process. Depending on the specific technology used, the power–heat output ratio is either fixed or more flexible. Flexibility comes at a price, but in operating the CHP plant there is less dependence on short-term exigencies of the electric and heat loads.

A starting point for a better understanding of the performance of CHP plants is an analysis of the characteristics of heat and power. An overview of some major features is given in Table 1.

Table 1. Major features of the products heat and power.

Feature	Heat	Power
Storage	Limited by time and temperature levels	Requires conversion, ie high investments, significant losses
Transport	Limited by distance, high investments, losses proportional to temperature, pumping power costs	Existing grids, generally available, losses are limited
Extent of the market	Local or non-existent	Interconnected regional, national, international
Service reliability	High requirements, inertia in heat mains and in end-uses limits the impact of outages	Very high requirements, high outage costs, instantaneous transmission

A negative impact on production facilities from demand fluctuations is anticipated by storing the final products or by modulating the facility (ie storing input materials and resources). Heat and power are two products that are not easy to store. With hot water it is technically feasible when the temperature is below evaporation, but it is costly and losses cannot be avoided. Newer technologies based on chemical reactions of the working fluid are not yet commercially operational. Some storage capacity in supplying low temperature heat is available because of the time delay between production and end-use (heat distribution networks and buildings function as a buffer between end-use and generation).

Electricity storage is a well-known major technical problem. The power in mechanical energy has to be converted, eg by flywheels; pressurized air; pumped water, or to chemical energy (eg batteries; hydrogen). This requires high investment, and conversion losses are an important factor, making pumped storage, thus far, the only applied technology for bulk storage.

Given the very limited possibility of storing heat and electricity and given the joint nature of the generation process, a CHP plant can face fluctuating loads only by modulating the process. Therefore, the choice of a CHP technology and plant in a particular application must take the modulation requirements into account.

Load fluctuations are considerably dampened when the loads of many customers can be aggregated. The dampening will be more successful the more customers are connected (law of great numbers) and the more variety they show. Bringing loads together requires the transportation of loads to be technically and economically feasible: haulage of process steam over long distances requires huge investments and involves significant losses. Long-distance transport of low temperature heat poses little technical problems and losses are limited but investments in networks and pumping costs are high. Therefore, the extent of the heat market is limited: process steam should be supplied to an industrial site (one or several factories) and low temperature heat to a local area (a building or group of buildings; a district or a city). In many places no heat transmission networks are available so the heat market is non-existent. This has been a major drawback for a large-scale extension of CHP in many countries.

Transport and distribution of electricity is an accustomed practice in all industrialized nations. The investments are made and long-lasting and both capital and organizations are available to keep grids ready for growing demand. Energy losses in a large interconnected power grid amount to 5–12% of electricity delivered and new technologies (superconductivity) can lower the losses further. The existing grids are the physical basis of the power market, extending from regional over national to international dimensions. Most power markets are far from free, being largely governed by some monopoly organization limiting access for other parties. Entering the power market is the single most important issue of independent power production and of independent CHP. Therefore the 'common carrier' and 'enhanced competition in electricity supply' discussions are of significant interest for the future of CHP.

When heat and power load fluctuations cannot be met completely either by the technology (storage and plant modulation) or by load aggregation, rationing the supply of heat or power by lowering the quality of service may be considered. This policy would make CHP very unpopular given the high to very high requirements put on service reliability for both heat and power.

When storage modulation and rationing are insufficient to meet the heat and power load patterns, it will prove necessary to provide back up production capacity for the single supply of at least one of the two outputs. The practical solution most CHP producers look for is to, on the one hand, instal additional boiler capacity for peak and reserve heat supply and, on the other to connect the CHP plant to the power grid functioning as an unlimited storage facility (allowing the selling of excess generated electricity and the buying of peak and reserve power).

CHP TECHNOLOGIES

The generic terms CHP or cogeneration cover a large variety of technologies and applications.[2] This is not the place to discuss in detail the various technologies. In Table 2, a brief overview of the most current CHP technologies is given. Newer developments such as combined cycle gas and steam turbines, steam injected gas turbines or fuel cells are not discussed here. The characteristic numbers used are average values so it is possible to find actual examples of better and worse cases.

The fuel flexibility of CHP plants is an often praised feature which, however, only applies to boiler fired plants. Gas turbines and engines require (light) fuel oils or gas. Investment costs (US$/kWe) of CHP plants are intimately related to economies of

Table 2. CHP generation technologies.

	Steam turbine		**Gas turbine**	**Reciprocating engine**	
	Back pressure	Extraction–condensing		Diesel	Gas engine
Prime mover	All boiler fuels		Gas; (light) oil	(light) oil	gas
Investment cost	high	very high	intermediate	low	low
Availability[a]	> 92%	> 90%	> 95%	> 98%	> 98%
Efficiency					
Energy combined	→ 88%	→ 85%	→ 80%	→ 80%	→ 85%
Electric only	–	→ 35%	→ 32%	→ 42%	→ 36%
Heat–power ratio	1.5 to 10	1.5 to 5	1.5 to 3	1.0 to 1.5	1.2 to 1.8
	(rising with higher temperature of exhausted steam)		(little dependence on the temperature of the recovered heat)		

Notes: [a]Availability is here defined as hours ready for generation to total hours within a year.

scale. Steam turbine plants show decreasing average costs over the entire capacity range of CHP projects. The unit investment cost remains high even for larger industrial CHP plants (around 50 MWe). Only the largest district heating CHP plants (300 MWe and more) can nearly exhaust the full economies of scale. Gas turbines are delivered in smaller units but below 10 MWe diseconomies of scale result. An inverted scale effect is observed in the engine market. Standardized packages deliverable from a few tens to a few thousand kilowatts bear a standardized low price tag. When larger unitary sizes are wanted they need to be custom built and come generally at a slightly higher price per kilowatt than the standard packages. All in all, the investment cost of engines is fairly low.

The availability of most CHP plants is generally higher than the availability of large power plants. Again the latest engines and gas turbines come up with very satisfactory results.

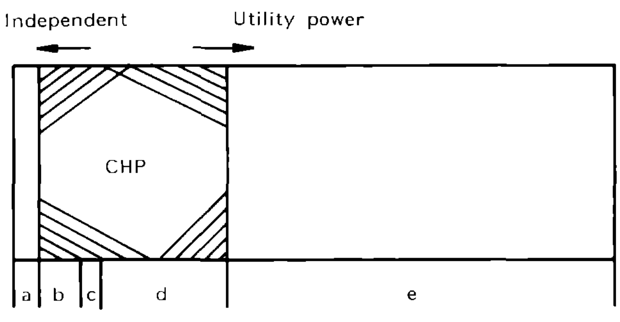

Figure 2. Situating CHP in the electricity generation business.

Notes: The rectangular area represents all power generated: a = independent power without heat supply (renewables such as hydro and wind; condensing power); b = independent industrial and commercial CHP for process steam and for heating; c = utility CHP for steam delivery to industrial processes (sometimes joint ventures; mostly heat side owned and operated by industry); d = utility CHP with district heating; e = utility condensing and hydropower.

The efficiency depends on the lay-out of the CHP unit and the numbers in Table 2 have to be considered as approximations of results in state of the art plants. Next to the overall efficiency of jointly produced heat and power the electricity only efficiency is shown; the latter numbers of course assume that the plant is equipped with some condensing or waste heat dispersing facility.

The heat–power ratio is a measure of the thermodynamic quality of the CHP process. Given a particular overall efficiency, the CHP process is better the lower the heat–power ratio. Steam turbine heat–power ratios can only approach those of the other technologies when the temperature of the exhausted steam is kept very low.

INDEPENDENT AND UTILITY CHP

CHP figures in most countries in discussions regarding independent versus utility power generation. This may be confusing as CHP is not limited to independent generation and independent generation is not limited to CHP.

In order to structure the discussion somewhat, the electricity generation business is shown as a rectangular box in Figure 2, accompanied by a detailed legend. It is obvious that CHP bridges the border between independent and utility power production and that border is further blurred by joint-venture projects (area {c} in Figure 2). Figure 2 also shows two other points: first, that CHP is the most important power generating technology of independent producers; and, second, that the largest share of CHP is still realized by utilities (in district heating and steam supply projects).

In Table 3 differences between industrial and commercial versus district heating CHP are summarized. Again we tried to represent the most current

Table 3. Industrial and commercial versus district heating CHP.

	Industrial and commercial	District heating
Ownership	Independent producers	Energy utilities
Market structure	Increasing competition	Lowering competition
Decision making	Private investment criteria (payback period; rate-of-return)	Social cost–benefit analysis (energy policy goal setting)
Heat delivery	No or limited costs	Major investments and operation costs
Electric grid connection	Mostly problematic	In house deals
Heat/electricity load patterns	User specific and very influential on CHP technology choice and profitability	Daily and seasonal fluctuations dampened by load management and heat storage
Technologies preferred	Gas turbines and engines	Steam turbines

Sources: See Ref 12.

state of affairs, and it may well be possible to point to exceptional cases in contradiction with the propositions of Table 3.

Most industrial and commercial CHP projects are owned by independent producers, whether by ownership of the plant or building or a third-party financier. In some cases utilities play the role of third-party financier. District heating projects are generally developed and operated by energy utilities. Publicly owned and locally bounded utilities are more prone to district heating than investor owned and nationwide utilities.[3]

As a corollary of the ownership structure, competition in the energy (especially power) market is stimulated by industrial and commercial CHP. Competition is discouraged when electric utilities or oil companies extend their activities to the heating market through district heating. The way investment decisions are made also corresponds to the ownership structure. Independent producers apply the various criteria of private investment decision making: (short) paybacks; (high) returns on investment; net present values implying their (high) marginal cost of capital as a discount rate. District heating utilities (mostly publicly owned) apply some kind of cost–benefit analysis with the major parameters (eg time horizon; discount rate; energy price forecasts) inspired by the energy policy plans of local or national authorities. Industrial CHP must withstand the market test of short-run financial interests. District heating CHP requires a long-term energy plan which also takes into account non-marketable externalities, such as lowering pollution in urban areas or increasing diversification in energy provision.[4]

Heat delivery costs in industrial and commercial CHP projects are nil or very low because CHP plants are constructed next to the heat loads. District heating requires high investments in transmission mains, heat exchangers, pumping stations etc; if it did not, it is possible that all buildings in the industrialized nations would have been supplied by a heat distribution network as they are now by the electric power grid.

The connection to the electric power grid of independent cogenerators is problematic in many areas. Electric utilities often raise artificial technical and economic barriers in order to discourage large customers taking steps to self-generate power. With district heating there is often a relationship of 'grace' between the electric and CHP/DH systems and electricity consumers even forgo their fair share of the economic advantage from CHP heat/electricity load patterns. These types of problems are very influential on industrial and commercial CHP projects and weigh more heavily on the technological choices when access to the power grid is discriminated against. Insufficient remuneration of power sold to the grid means, for example, that most independent CHP projects are scaled on the electric loads of the industrial or commercial plant and not on the often more important heat loads. From a societal point of view good CHP opportunities will be overlooked by this practice of capacity planning. CHP plants in district heating are dimensioned on the heat loads (back-pressure plants) or on the heat and power loads jointly (extraction–condensing plants).

The technologies preferred by independent cogenerators are mostly gas turbines and engines because of their suitable scale, modular and packaged supply, quick start and high reliability. In district heating, steam turbines are the most usually installed CHP units.

THE ECONOMICS OF CHP

Many factors that govern the economics of CHP projects have already been considered in the previous sections. These factors are mostly analysed in three interrelated groups: load factors, plant characteristics, and terms of trade with external energy markets.

Patterns of heat and electricity demand and annual operating hours set the technical and economic limits for the technological choices. The type of technology, the scale of the plant, and the type of prime mover all depend on the loads to be met. Plant characteristics such as capital cost, operating and maintenance expenses, efficiencies, etc also, of course, have their impact on the profitability of CHP projects. But what makes CHP projects so particular is the interference with energy markets. On the one hand, the market of fossil fuels sets the price conditions for the prime mover (natural gas, oil or coal in most CHP plants), the energy input being a major cost item of all CHP plants. On the other hand, one of the CHP outputs, ie heat or steam, competes with single heat or steam raising facilities also fired with fossil fuels.

The relationship to the power market is of still greater importance for the economics of CHP. Independent cogenerators deal with the power grid in three ways: first, they buy power from the grid to meet peak power loads or to substitute purchased power for self-generated power when this is an economic option during particular periods; second, they sell their surplus power production to the grid; and, third, they take up back up power from the grid when their own plants are out of order. In most countries these transactions are not yet regulated in such a way as to guarantee the independent producers non-discriminatory access to the power grid.[5]

On the issue of complementary power, the satisfactory practice of applying general tariff conditions on the peak and additional electricity consumption of cogenerators is in force in many areas. Remuneration of power sold to the grid remains a critical point even when the principle of 'avoided costs' is widely worshipped. For independent CHP plants the provision of back up power by the grid remains a major problem. Even in California, a recent public utility commission's decision priced back up power high, approving an expensive flat fee for connection capacity (in some cases as much as half the customer's electricity bill) that must be paid regardless of amount of power used.[6] Loaded back up power payments act as especial disincentives to industrial and commercial investors in CHP.

Judging the economics of CHP requires, first, a thorough understanding of the energy flows within an industrial or commercial plant; second, a good knowledge of CHP technologies and their performance; and, third, a sound insight into large energy markets. Because heat and load profiles may be very variable from hour to hour, day to day and season to season, and as electricity tariffs in most countries become more and more time of day, daily and seasonally adjusted, it will prove wise to make a detailed study of the CHP projects under consideration. Relying on back of envelope calculations of average conditions can promise rose gardens but will cultivate more thorns than flowers. Detailed analysis will, for example, refute the common belief that higher fuel prices always favour the profitability of CHP. Actually the relationship between fuel prices and CHP's profitability depends very much on the terms of trade with the power grid and on the composition of the electricity industry supplying that grid. When electricity prices are not very sensitive to changes in fossil fuel prices (eg because of a large nuclear or hydro share in the generating capacity) increasing fuel prices usually lower the profitability of CHP although it is a technology which saves energy to a significant extent (Figure 1).

A clear cut judgment of the economics of CHP is also difficult because of the problem of joint costs when generating two outputs simultaneously. The theoretical propositions of cost allocation based on marginal revenues contributed by the respective outputs, are in practice replaced by some rule of thumb (district heating CHP) or by the outcome of a regulatory process or a bargaining process between independent producers and utilities.

To keep the financial balance of CHP projects in line decisions about the right technology and capacity and about the suitable way of operation must be keenly sought. CHP project developers discern two philosophies: first, the exigencies of the electric loads considering heat as a byproduct can be followed; or, second, the exigencies of the heat loads considering electricity as a byproduct. The first philosophy does not exploit the CHP opportunities to their full extent; and the second is dangerous when insufficient attention is devoted to the efficient generation of (expensive) power. Therefore, the best CHP philosophy can be summarized in the following paradox: a CHP plant should maximize its electric power output, subject to giving priority in meeting the heat loads. Of course this rule must be applied with due respect for practical circumstances.

CHP AND ENERGY MARKETS

The viability of CHP depends greatly on the evolu-

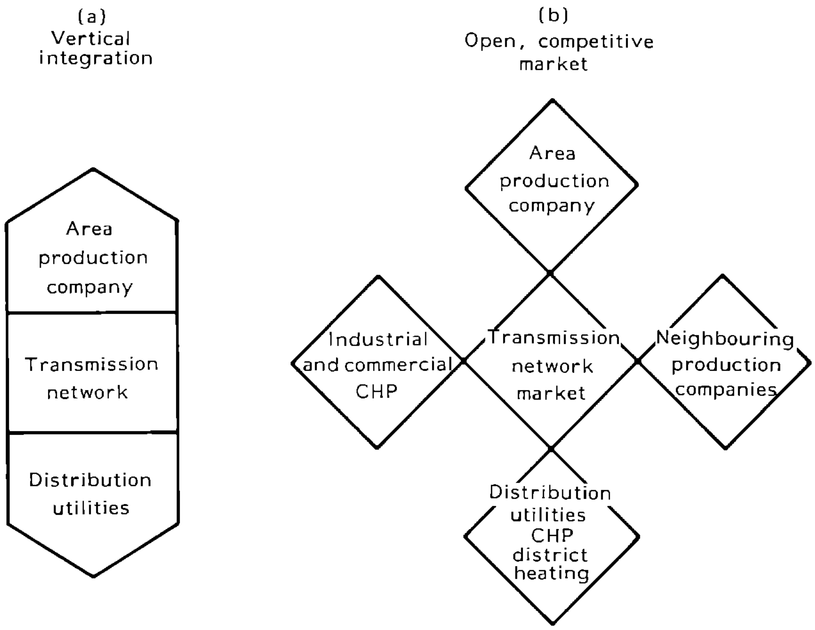

Figure 3. Market structures in the power industry.

tion of the various energy markets. A CHP plant is an energy conversion unit with fossil fuels as the input and heat and power as outputs. In other words, CHP is linked to three energy markets: the market for fossil fuels (or one of the fossil fuels depending on the CHP technology installed); the heat market; and the power market. CHP's profitability can vary according to whether the relevant markets all develop in a favourable or unfavourable direction.

We have no knowledge of a detailed study on the relationship between CHP development and market developments in, for example, coal or natural gas. Undoubtedly there have been important influences. In several German cities DH gained considerable support because the supplying CHP plants were fired with domestic (local) coal.[7] The thrust of an expanding natural gas market in Europe also stimulated the boom in gas turbines and gas engines for CHP.[8]

Although heat takes the largest share of energy consumption in the industrialized world, heat markets are not well developed. This is due to technical and economic problems of heat storage and of heat transportation. Heat distribution networks are owned and operated by monopolists and access to deliver heat to the network always goes through a bargaining process. Either because of regulatory prescriptions or because of considerations about competitiveness, heat prices are generally narrowly linked to the evolution of fossil fuel prices. The extension of CHP is hampered significantly because of the embryonic nature of heat markets in most nations.

The power market is the third CHP deals with.[9] In all industrialized nations, power markets are well developed and governed by mighty public or investor owned companies. Access to the grid for independent producers is regulated and can range from nearly free market conditions to bluntly imposing barriers on all entries. Independent generation and CHP face the most difficulties when the power companies are vertically integrated from production to final distribution (Figure 3, part a). With vertical integration there is no place left for market forces and each customer is served at subscription or at individually negotiated rates.

In order to gain greater transparency and competition in the power business vertical integration will have to be broken up into an open, modular structure (see part b in Figure 3), bringing generation, transmission and distribution under separate control. In this configuration the transmission network is the marketplace operated as a common carrier but for technical reasons (frequency regulation; equilibrium of active and reactive power etc) controlled by a central intelligent authority playing the role of a broker between supply and demand. Transactions among the various parties will be based on real costs and prices may tend towards marginal costs.[10] This would ease the major problems independent generators now face: wheeling would be a common activity; power purchased at and delivered to the grid

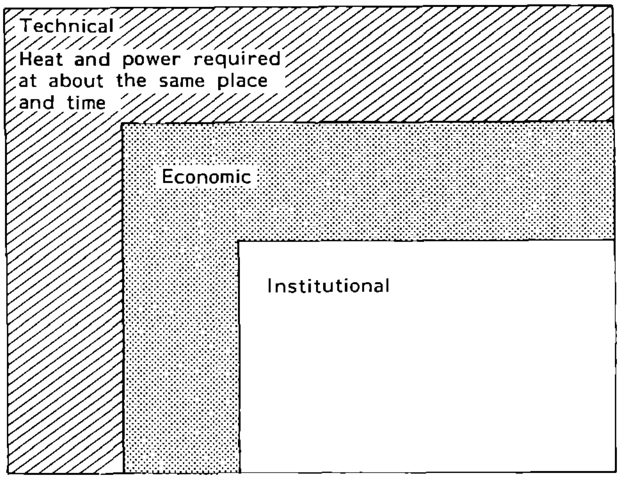

Figure 4. The levels of CHP potential.

would be priced at its marginal value; back-up power would also be available at its true cost.

Reality in most nations is still far away from this economist's utopia. The discussions on and steps towards raising competition and restructuring the electricity sector have been very active during recent years particularly in the Netherlands, the UK, and the USA. The EEC has also recently exerted a continuous push towards more competition.

At present, the impact of the trend towards more competition on CHP development is not yet clear. Independent generators generally favour the opening of the power market. For district heating the situation is more ambiguous. District heating and its related CHP projects require a low-discount, long-term planning attitude to withstand the present-day competition from available heating systems (especially natural gas). This, however, does not entail that utilities developing district heating should be a part of a vertically integrated energy company. On the contrary, locally bounded utilities have been the mavericks in developing district heating (eg the typical *Stadtwerke* in German cities). Because these utilities also build their own CHP generating capacity they provide a check on the monopoly power of the nationwide power generators.

The relationship between cogenerators and the power grid is a complex one and interferes with the efforts of policy makers and regulators to enhance competition in the sector. The future of CHP is heavily dependent on the way the power sector is regulated in various nations.

CHP AND ENERGY POLICY

CHP is a many-sided issue and non-experts should not be blinded by the beautiful Sankey diagrams of improved energy conversion efficiencies (Figure 1). The physical principles of CHP are well known, and technically CHP poses little problem when the right technologies are fitted to the right applications. Undoubtedly there is a very large potential technically ready for installing CHP units: every energy consumption centre where heat and power are demanded at about the same place and at about the same time, is a candidate.

Physical and technical opportunities also need to stand the test of economic feasibility. Here many projects fail because of mismatching heat and power loads; disparate energy price evolutions of fossil fuels, and of heat and electricity; insufficient scales or utilization times etc. The set of economic CHP applications is significantly smaller than the set of technically feasible CHP (Figure 4). Most people can live with this reality.

Unfortunately, in many areas the economic potential cannot be realized because of institutional barriers. A variety of these barriers have been mentioned eg the well-known pay back gap between decentralized and centralized decision making about energy projects, regulatory prescriptions, unequal tariff conditions imposed on independent generators by monopolistic power companies, discriminatory discounted tariffs for large electricity consumers pending towards self-generation etc.

The discussion about CHP has revolved mostly around the measures and means necessary to match the institutionally feasible set to the economical one. For district heating CHP:

> experience indicates that the type of economic and political system is a most decisive factor in the effective use of DH and CHP. Admittedly, the most widespread use of DH and CHP is found in the countries with a centrally planned economy in which the delivery of heat, and to some degree also electricity, has been considered a social commodity. Those countries or companies who advocate short pay back periods for investments in CHP/DH systems have not been very successful in establishing such systems due to their unattractive commercial return.[11]

In other words a global, long-term energy policy that shelters options with long pay back periods from alternating market forces is needed. This has also been true for the development of nuclear power. It has sometimes been argued that if the massive support for nuclear power had been directed towards district heating/CHP, a better energy situation would have resulted. Energy planning with due consideration to district heating and CHP is more than just a paper blueprint. The planning process and its realization must be supported by skilled utilities, manufacturers, engineering/contracting companies etc. In some countries a flourishing DH–CHP industry is a solid base to keep the CHP option standing against other powerful energy interests.

Industrial and commercial CHP generally cannot fall back on similar well organized and well funded interest groups. The crucial issue seems to be a more equitable access for independent generators to the power market, in order to be assured of the right tariffs for buying and selling electricity and of back up capacity at real cost. For several decades CHP industrial generators were dependent on the rule setting of centrally organized electricity companies. They could not compete with the growing power of the seemingly inexhaustible economies of scale of the nuclear and coal fired baseload stations. In the 1980s major shifts have occurred. There is a cap on the extension of large-scale coal and nuclear stations in many industrialized nations. There is a trend towards more competition in the power business, generally supported and sometimes headed by regulatory and official authorities (eg the EC). Environmental policies favour energy conservation and, therefore, also CHP.

In many countries, there is pressure on governments to subsidize CHP because its externalities are less negative than those of central power plants. However, before starting subvention schemes it should be warranted that power trading with the central grid is set on an equal footing; if not, a smaller or larger part of the CHP subsidies will glide into the pocket of the central power companies.

The future of CHP looks definitely brighter than in the past. Accompanying this transition with timely measures is the major task of a pro-CHP energy policy.

CHP SERIES

We hope to have highlighted in this introductory paper the fact that CHP is a complex business and that we should not be blinded by its thermodynamic superiority. Thorough study of technological, economic, institutional and policy factors is needed before embarking on major projects. Of course many of these factors are time and site specific, and that is why we want the *Energy Policy* series articles to be down to earth. We have invited several authors to tell us about the CHP experience in their own country, to show us how CHP is realized, what factors were decisive for success or failure, what barriers were or were not overcome etc. Parallel to the case study articles from various countries, a number of articles about methodology (eg the economic appraisal of CHP investments) and about principles (eg organizing and pricing access to the power grid) are scheduled.

Because the CHP discussion is vivid in several nations, in order to keep up with the pace of the discussions, we have reserved some space for contributions that may express firm disagreement with articles or that add valuable information. Authors are invited to submit their proposals to the guest editor.

[1]W. Reynolds and H. Perkins, *Engineering Thermodynamics*, McGraw Hill, New York, 1977; or for a clear introduction, W. Reynolds, *Energy: From Nature to Man*, McGraw Hill, New York, 1974.

[2]Information on CHP technologies can be found in specialized publications by manufacturers (eg Siemens, Asea Brown Boveri, General Electric etc). Also standard works are available, see R. Diamant, 'Total energy', *International Series in Heating, Ventilation and Refrigeration*, Vol 6, Pergamon Press, Oxford, UK, 1976; or Verein Deutsche Ingenieure, *Blockheizkraftwerke*, VDI-Verlag, Dortmund, 1986.

[3]A. Verbruggen and C. Marcelis, 'Institutional constraints on district heating and cogeneration feasibility', *Proceedings Eighth Annual International Conference, International Association of Energy Economists, Tokyo, June 1986*, pp 497–512.

[4]World Energy Council, *District Heating/Combined Heat and Power. Decisive factors for a Successful Use – as Learnt from Experience*, June 1991, p 63–64.

[5]In the USA there is a vast literature on this issue following the implementation practice of PURPA, such as articles in *Independent Power News, Cogeneration, Public Utilities Fortnightly*, and publications by the Federal Energy Regulatory Commission etc.

[6]J. Summerton and T. Bradshaw, 'Towards a dispersed electrical system: challenges to the grid', *Energy Policy*, Vol 19, No 1, January 1991, p 31.

[7]The success of district heating and CHP in Saarland and in the Ruhr area is partly due to this link with the coal industry.

[8]The Netherlands and Italy have been ahead in applying gas fired cogeneration units.

[9]In the 1980s deregulation of power supply, privatization of utilities and enhancing competition were favoured topics in the energy policy arena. See T. Berrie, 'Improving marketplace efficiency in the non-oil energy sectors', *Energy Policy*, Vol 15, No 4, August 1987, pp 315–328. Also *Privatizing Electricity*, Cm 322, HMSO, London, February 1988, and the stream of publications following the privatization process in the UK.

[10]See Berrie, *ibid*; and S. Littlechild, 'Spot pricing of electricity: arguments and prospects', *Energy Policy*, Vol 16, No 4, August 1988, pp 398–403.

[11]*Op cit*, Ref 4, p 64.

[12]Most of the issues summarized in the table and discussed in the section are scattered in many publications, eg International Energy Agency and Danish Ministry of Energy, Workshop on the Regulatory and Institutional Aspects of Combined Heat and Power Production and District Heating, Copenhagen, 15–17 June 1988, proceedings; or Institute of Energy, CHP: Creating Higher Profits, Seminar held in London, 16–17 May 1991, Proceedings.

[13]*Op cit*, Ref 4, p 44.