COMBINED HEAT AND POWER AND ELECTRICITY GENERATION IN BRITISH INDUSTRY 1983 - 1988

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Combined heat and power and electricity generation in British industry 1983–1988

A Statistical and Economic Survey

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Foreword

BY THE SECRETARY OF STATE FOR ENERGY

The publication of this Survey report on "Combined Heat and Power and Electricity Generation in GB industries" marks a major advance in our knowledge of the extent, composition and characteristics of both private electricity generation and of industrial combined heat and power (CHP).

It contains the analysis of Survey data relating to 1983, and supplied in 1984 on an entirely voluntary basis by executives at some 140 industrial establishments. Without their conscientious and painstaking co-operation the outstanding high response rate of the Survey could not have been achieved and the value of the Report would have been considerably diminished. To each of them I wish to convey my thanks.

Now that the Energy Act, 1983 has become law, I believe industrial CHP has an important role to play in the future energy scene. To assess its potential, and to remove any remaining artificial constraints on its wider application in the future, a clear appreciation of its role today, and of possible limitations to its further development, is essential. As Abraham Lincoln said, "If we could first know where we are and whither we are tending, we could better judge what to do and how to do it." This Report meets precisely this need. Indeed, as a basis for monitoring future progress and for considering policy options in this field to facilitate its optimal development, it will be invaluable.

I expect that readers will find this report both useful and informative. Encompassing, as it does, every major generating plant in the private sector, together with a study of the constraints on CHP and an assessment of future CHP installations prospects over the next few years, it would appear to represent a 'World first' in its field - and as such a fitting contribution to Energy Efficiency Year.

PETER WALKER
Secretary of State for Energy

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INTRODUCTION, HISTORICAL BACKGROUND & OVERVIEW

(by Mr Eric H M Price, Undersecretary, Economics and Statistics Division)

1 The "Survey of Combined Heat and Power & Private Electricity Generation in GB Industry 1983" initiated by the Department of Energy represents the first of two studies into combined heat and power (CHP) in industry. The study described in this report covers existing private generators of electricity; in contrast, the second, the study now in preparation by Ove Arup & Partners, was designed to establish the prospects for co-generation of electricity in those firms and sectors of industry with little or no experience to date of combined heat and power.

2 This present report constitutes a Department of Energy assessment of replies to postal questionnaires despatched by the Department of Trade and Industry's Business Statistics Office to every electrical generator listed as contributing regularly to the Department of Energy's Quarterly Survey, but, in addition, other private generators not on that list, were contacted and kindly agreed to participate in the Survey. Notwithstanding the entirely voluntary nature of the Survey, an extremely high response rate, (representing some 95% of the electricity generated in the private sector, excluding stations owned by the Atomic Energy Authority) was obtained.

3 The report contains detailed statistical tables on plant capacity, electricity generated and fuel consumption for 1983. Past trends in plant retirements and in installations of new capacity as well as prospects for the future, are also covered. Small scale CHP and CHP/District heating (the latter being used mainly for commercial local government and domestic users) are excluded.

4 Private Generation and Industrial CHP 1953-1983

Four Surveys of private generation have been undertaken between 1953 and 1983. The first, in 1953 was designed by the then Ministry of Fuel and Power, to "Survey the Potentialities for Back Pressure Generation of Power;" the second was undertaken by the Ministry of Power entitled a "Survey of Electricity Generated Outside the Public Supply System in 1963"; and a third Survey was produced by the Department of Energy in 1977 and published as "Inquiry into Private Generation of Electricity in GB." The results of the latest Survey for 1983 are outlined in this report.

5 From these Surveys a clear and reliable impression of the composition of private generation over this period can be obtained. The basic statistics are given below. All estimates are measured in terms of net output (ie minus a 5% allowance for electricity used in the boiler and generating plants).

OUTPUT OF CHP, PRIVATE GENERATION OF ELECTRICITY AND ELECTRICITY CONSUMPTION IN GB INDUSTRY (1955-1983)

	CHP	Total Private Generation	Electricity Consumption	CHP as a Percentage of:-	
	TWh			Electricity Consumption %	Private Generation %
1953	6.01	10.66	38.92	15.4	56.4
1963	7.50	12.95	69.23	10.8	57.9
1977	9.95	15.83	102.50	9.7	62.9
1983	6.74	11.55	90.42	7.5	58.4

6 Electricity consumption in UK industry more than doubled between 1953 and 1983, yet production of electricity from CHP plants increased by only 12%. CHP's share of electricity consumption in GB industry declined from 15.4% to 7.5%. These figures mask significant changes between industries and are considered later in this report.

7 Types of CHP Plant

There are three basic types of prime-movers used for CHP plants, viz steam turbines, gas turbines and internal combustion and reciprocating engines.

(i) Steam Turbines

These represent the majority of CHP plants in service and comprise back pressure, passout and passout condensing sets. Some of the energy contained in high pressure steam produced in a boiler is converted to mechanical power via a turbine and then to electricity via a generator. The steam at reduced temperature and pressure is passed to works for use as process heat or space heating. In passout condensing sets a higher proportion of the energy can be transofmed into electricity via the condensing mode - but at the expense of lowering the overall efficiency of converting fuel to heat power.

(ii) Gas Turbines

These are becoming progressively more popular for new installations because of their low heat to power output, their relatively low capital cost and the availability of high grade heat from the exhaust. A gas turbine consists basically of a piece of turbo-machinery in which air is compressed and fuel is burned. The energy produced by the expansion of hot gases reverting to atmospheric pressures is used to drive a separate power turbine, the latter may be linked to a generator. The high temperature exhaust gases can be used directly (eg for drying) or indirectly via a waste heat boiler (in which the heat from the exhaust converts water to steam).

(iii) Internal Combustion and Reciprocating Engines

A relatively large number of mini-CHP Schemes, and a small number of large industrial schemes, are based on internal combustion or reciprocating engines. The engines are used to generate power directly via a turbine and generator and the waste heat is recovered from the engine's exhaust and cooling system.

(iv) Apart from these three basic types, more complex schemes can be designed eg waste heat boilers can be 'after-fired' and the steam from a waste heat boiler (linked to gas turbine exhaust) can be fed to a steam turbine to produce a combined cycle. The choice of the fuel for a gas turbine and internal combustion engine is normally restricted to either oil or gas, whereas a boiler feeding a steam turbine can be designed to burn coal or waste as well as oil or gas.

8 Factors Crucial to the Economics of CHP Generation

To evaluate the findings of the Survey, and in particular to consider future prospects, some appreciation of the essential economics of CHP may be helpful. CHP schemes are designed to produce both heat and power (usually in the form of electricity) so as to cater either partially or totally for the requirements of an industrial site. Some may, on occasions, produce electricity surplus to the site's requirement which is available to be sold to the local Electricity Area Board.

9 CHP systems are therefore generally more efficient in energy terms than systems designed to produce either heat or electricity separately. But whether they are economically efficient - and this has to be the main concern of the industrialist - is a more complex issue.

10 The economics of industrial CHP schemes are crucially dependent upon a number of special factors - as well as upon the generality of factors that affect all investment projects. These special factors include:-

(i) the extent to which the capital and fixed operating costs of CHP plant are above those of 'package' boilers;

(ii) the current and expected 'on site' steam to power ratio;

(iii) the price differential between the fuel consumed in the private generator's plant and that used by the public supply;

(iv) the price the company can obtain for its sales of electricity and the cost of back-up supplies available from the public utilities under Energy Act Tariffs (see Annex 17);

(v) the economic life expectation of the plant, which in turn, will depend upon the fuel to which it is dedicated, and the load factor on the plant. This will depend, more generally, upon the prospects for demand for the main product lines of the establishment and the technology used in their production.

A brief indication of the relevance of these factors may assist the reader in interpreting the findings of the Survey and in drawing conclusions about the future potential of CHP.

11 Capital Costs of CHP Plant

CHP plants, which are in the main high pressure steam systems, involve substantially higher capital expenditures than low pressure boiler systems. The crucial issue therefore becomes whether the value of the electricity saved, less the cost of extra fuel and other operating costs, is sufficient to enable the extra costs of the CHP to be recouped within an acceptable payback period, or alternatively to yield an attractive dcf internal rate of return.

12 Typically, the capital cost of a site erected high pressure water tube boiler with the necessary ancillary equipment, including turbines and generators for CHP output, can be three to four times more expensive than a low pressure 'package' boiler to serve normal process and heating requirements only. The value of the benefits of CHP to the industrialist, therefore, have to be very considerable if he is to be able to justify this additional capital expenditure and the associated addition to his risk exposure. (Site erected small high pressure CHP steam systems have an even higher capital cost 'penalty' to overcome to become economic.) It is for this reason that several companies are now offering lower cost 'package' water tube boilers.

13 <u>The Steam/Power Ratio</u>

The viability of any CHP scheme can be undermined if there is a dramatic fall in the steam/power ratio. Such a decline can occur through successful energy conservation measures, technical change and variations in the final product mix. Steam turbine systems tend to produce steam to electricity in the ratio of 5 to 6 MW(T) to 1MW(E)≠ or higher. Conversely, a gas turbine or diesel powered unit, both with heat recovery, will produce steam to power in a ratio of 1-2 MW(T) to 1 MW(E). Falls in the steam/power ratio have been the norm throughout the post-war years. However, prior to 1973, when oil prices were low, any fall in the steam/power (ie electricity) ratio could quite easily be accommodated, either by utilising the condensing mode on passout condensing sets, or simply by running the steam through separate condensing turbines. Indeed, some large establishments operated, and continue to operate, their condensing turbines during 'load management' periods or to balance load on their high pressure boiler plant. (With the low oil prices now prevalent, it may be economic to increase the utilisation of these plants.)

14 <u>Fuel Prices</u>

A firm investing in a steam driven CHP system has to take a long view. Boilers and associated plant have very long lives, some 30-40 years, are relatively inflexible (ie cannot be readily adapted to changing steam/power ratios), are immobile, (ie cannot be easily dismantled and rebuilt elsewhere), and involve a heavy capital expenditure which takes at least 5 years to recover. In these circumstances, changes in relative fuel prices can make a CHP project unprofitable. This is because after commissioning, a CHP plant can be

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≠ These should not be confused with DH/CHP Schemes which have lower ratios because they require low temperature heat.

profitable to operate provided its variable costs for producing steam and electricity jointly (ie in the main, its fuel input costs) are lower than the alternative involving the costs of steam from a heat-only boiler together with those of electricity purchased from the public supply. (Some 70%-80% of the delivered cost of public supply electricity to large industrial sites reflects the cost of primary fuel inputs.) If the price of fuel consumed by the electricity utility (ie mainly coal) is significantly lower than the fuel used by the CHP plant (ie usually gas or oil), the CHP Plant may become uneconomic to operate. (Here it should be noted that the rapid escalation in oil prices in 1973 and 1979 led to the closure of many CHP stations despite their higher overall technical efficiency.) Conversely, if oil and gas prices decline relatively to coal prices, the profitability of a CHP plant using these fuels may be significantly improved.

15 Thus, changes in the relative prices of different fuels, the differences in the magnitude of fuel costs in the composition of total variable costs and differences in the energy efficiency of the alternative power sources are factors critical to the economic operation of CHP plant once built. Many industrialists contacted during the survey, believed that over the next 20 years fuel prices would remain highly volatile. There was evidence, consistent with this view, that companies on several major sites had sought to minimise their risk of exposure to fluctuations in fuel prices by taking advantage of the coal-firing scheme to incorporate a multi-fuel capability into their boiler plants.

16 A new development in recent years has been that of 'second' and 'third' generation gas turbines. There has also been interest in large diesel engines. Both have reflected the desire to produce much higher ratios of electricity to steam than can be produced in conventional steam systems. Moreover, these prime movers have a much lower capital cost per unit of electrical output. The economics of diesel engines and gas turbines (favoured by firms in the chemical and refinery sectors) are sensitive to any change in the relative price of the fuel to which they are dedicated (oil or gas) and the fuel (mainly coal) consumed by the public supply utilities.

17 <u>Importance of Industrial Structure and Product and Process Change to CHP</u>

Currently, four principal sectors account for 88% of the CHP generation in UK industry. These are: chemicals, refineries, paper and board, and food and drink. The chemical and refinery industries alone accounted for, 70% of all the production of electricity from CHP plants in 1983 and 65% of the capacity. The reason for this is that both these industries use a vast amount of both heat and power for process and distillation in the manufacture of a range of chemical and pharmaceutical products. A breakdown of CHP generation and capacity by industry for 1983 is given below:-

OUTPUT OF ELECTRICITY AND CAPACITY OF CHP PLANTS IN GB INDUSTRY, 1983

INDUSTRIAL SECTOR	Output of Electricity in CHP Plants TWh	Capacity of CHP Plants MWe
Chemicals and pharmaceuticals	3.3	962
Refineries	1.6	379
Paper and Board	0.9	290
Food and drink	0.5	205
Other Industries	0.8	221
Total Industry	7.1	2057

18 Changes in the amount of electricity produced by CHP plant in each industrial sector between 1955 and 1983 (considered in greater detail in annex 16) are as follows:-

OUTPUT OF ELECTRICITY FROM CHP PLANTS, 1955 AND 1983

INDUSTRIAL SECTOR	1955	1983	Change 1955-83
	TWh	TWh	%
Engineering	0.7	0.1	- 86%
Food, Drink, Tobacco	0.2	0.5	+ 150%
Chemicals	1.8	3.3	+ 83%
Refineries	0.2	1.6	+ 700%
Paper and Board	1.8	0.9	- 50%
Iron and Steel	0.5	0.4	- 20%
Textiles and Leather	0.3)		
Coal Mining	0.4)	0.4	- 25%
Other	0.5)		
Total	6.3	7.1	+ 13%

19 Overall, changes in private generation and industrial CHP over time have been closely associated with changes in industrial structure and industrial processes. Lower electrical generation from CHP plants in paper and board, engineering and coal-mining have been compensated by substantial increases in the output in chemicals, refineries and the food and drink industries (data showing trends in electrical output for different industries are given in Annex 15).

20 The following examples illustrate how circumstances have changed in certain key industries:-

(i) The decline in CHP in the engineering industry has been associated with a reduction in vertical integration and with changes in manufacturing processes. At one time many engineering firms had their own blast furnaces and foundries. They used tail gases supplemented by purchased fuels to feed high pressure steam boilers which typically supplied steam to propel steam hammers and steam drives whilst the residual steam could be used for space heating. Today, these blast furnaces have been closed and most of the steam driven applications have been supplanted by electricity, thereby reducing the steam/power ratio. The residual process and space heating requirement is insufficient to justify a CHP system.

(ii) In coal mining individual pits once were equipped with on site power stations, supplying both heat and power: today they buy-in their electricity.

(iii) In the paper and board industry a most significant reduction in the capacity and output of CHP plant has taken place. Here CHP systems have been replaced with package boilers and purchased electricity. The ratio of electricity to steam has risen at each stage of the paper making operation. At the feedstock stage, more electricity is required for de-inking and cleaning waste paper, which now represents a much higher proportion (a quarter to a half) of the fibrous material. Second, at the wire and press stages, more water is now extracted through mechanical means involving more electrical input so that less steam is now required for drying. Moreover, heat recovery systems now save low grade heat which further reduces the demand for steam, and invariably increases the demand for electricity to operate the system. At one paper mill the existing CHP plant, installed many years ago, is capable of producing steam to electricity ratio of 8:1. This was perfectly adequate when the plant was installed but, because of lower steam demand and increases in the electrical power requirements, the current ratio is 3:1 so that the CHP plant has to be run on part load: hence more than 50% of the plant's electricity requirements have to be imported from public supply.

(iv) The chemical industry has been experiencing similar problems. On some sites, under the influence of new technology, the steam/power ratio has fallen by 30% or more over the past 20 years. On one site a process using 1950s technology requires a steam/power ratio of 9:1, whereas a similar product using 1970s technology has a steam/power requirement of 2:1.

These industrial examples illustrate the trends that are influencing the application of CHP in this country.

21 It is clear that the decline in industrial steam/power balances is likely to continue for many years. This implies that any appraisal of a CHP project will need to take account of future, as well as of current, needs with regard to steam and power. To establish future steam/power requirements, a view has to be taken of the levels of output, product mixes and manufacturing processes some ten years ahead. The needs of the market place are thus crucial to any assessment of the economic viability for any new proposed combined heat and power plant.

22 The Survey in this report sought to establish the extent of recent changes in CHP plant and respondents' perception of those likely in the near future. Until this Survey, a complete record of modern CHP plants did not exist. Whilst the Survey indicates that expectations about withdrawals from services of generating capacity exceed those concerning new capacity to be commissioned, a large part of this will consist of old inefficient condensing or passout condensing turbines, whereas the new capacity will be high efficiency back pressure steam turbines or gas turbines - both particularly suitable to CHP operation - operating at higher overall load factors. Because of these counter-balancing forces, the survey indicated little change in the output of CHP plants over the next few years.

23 There could also be a significant demand for small scale CHP plants with outputs in the range 1 to 6 MWe. The forthcoming report by Ove Arup & Partners (referred to in para 1 above) will clarify the future prospects for such plant.

24 The last two years, however, have been ones that have experienced remarkable changes in the industrial scene, with sharply rising corporate profits and liquidity, lower interest rates, higher labour productivity and generally higher output. On the energy scene, oil and coal prices are sharply lower and other energy prices have declined in real terms. Moreover, the availability of more attractive tariffs from Area Boards as a result of the Energy Act 1983 has become more widely known.

25 As a result, the prospects for CHP may now be rather different and better - than those perceived in 1984. This could well indicate that where demand exists, CHP, in one of its several forms, may play an increased role in the energy pattern of the future.

SUMMARY

THE ROLE OF PRIVATE GENERATION, 1983

1 The Survey of Combined Heat and Power and Electricity Generation in GB Industry 1983, sought to cover 150 establishments (of which 147 were located in manufacturing industry).

2 Key findings from the Survey are:-

All Private Generation

(i) These 150 establishments produced a total of some 13 TWhs of electricity from 3.6 GWe of generating plant,

(ii) They accounted for around 99% of electricity generated in the industrial sector and 95% of the electricity generated outside the public supply,

(iii) This represented some 4.5% of total electricity generated in Great Britain,

(iv) The output of the 147 manufacturing establishments - 12.3 Twh - represented just under 13% of electricity consumed by industry.

(v) Of the 13 TWhs of electricity, 5.9 TWhs (45%) was generated from non-CHP plant including steam systems incorporating condensing turbines, hydro stations and gas turbines and diesel engines without heat recovery used in the main for 'peak lopping'.

All CHP Generation

(vi) The remainder, some 7.1 TWh, or 55% of the electricity produced, came from Combined Heat and Power (CHP) plants. This accounted for 7.5% of the electricity consumed by industry,