Future Challenges for CHP in the UK
and
Continental Europe

F.Starr PhD, FIMMM, C. Eng : March 2010

Abstract:

An objective, but broadly sympathetic, view has been taken of the future of cogeneration in the UK. Although its current problems, appear to have resulted from the market economy, the basis to these difficulties is structural. These arguments are supported by discussions on the electrical and CHP efficiencies of various prime movers. These include IC engines, gas turbines, large scale power plants, nuclear CHP, and micro CHP systems. The future could be difficult too, with CCGT plants being developed to reach electrical efficiencies in the 70-75% range, natural gas prices going even higher, and energy conservation reducing heat demand to a fraction of that today. Renewable heat is both a challenge and an opportunity. The way cogeneration will need to change varies from country-to-country.

Only Denmark appears to have a well thought out policy, in which fossil fuels will be phased out and biomass will supply a greater fraction of the fuel required for CHP and pure district heating schemes. The UK has a huge natural gas infrastructure which creates serious problems for the advancement of CHP in this country. For other European countries, which have extensive town based district heating systems there is a strong argument for basing these on advanced CCGT-Cogeneration or coal based steam plant with CHP. The biggest concern for CHP is that, because it is fossil fuel based, the long term prospects must be in some doubt.

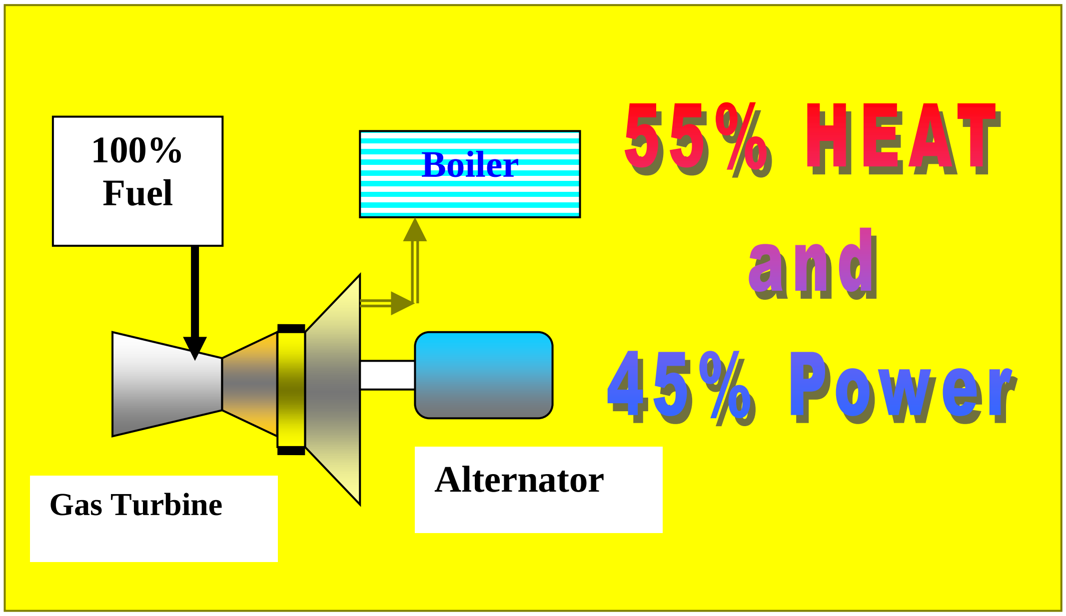
Contents

1. Introduction

CHP (Combined Heat and Power) or cogeneration as it is also called, seems such a good idea, and has almost universal support outside of the mainstream power plant sector. It is well known that the generation of electricity using energy from coal. oil or gas and nuclear always results in a large amount of waste heat being thrown away, usually in the form of cooling water. Why not, therefore, use used this waste heat, instead of, for example, in the case of the UK , burning our fast diminishing reserves of natural gas to heat our homes, factories and workshops? Why not too, use the efficiency of CHP as a mean of reducing the emissions of CO_2, thereby mitigating the effect of power plant operation on green house warming?

Figure 1 shows the usual cheerful schematic of **"How CHP Works",** where fuel is consumed to produce both electricity and heat. This is the simplistic message that goes out to the public and, more importantly, to our political masters. One aim of this paper is to demonstrate that the energy saving potential of cogeneration is not so clear cut, even at the present time. But what about the future when CHP is perceived as one of the options for a greener cleaner world?

Figure 1 : An Idealised CHP System



The author of this report has much sympathy with the idea of cogeneration, and was indeed the person who began the Stirling engine Micro CHP Programme in British Gas, back in 1988. But it is clear that many supporters of cogeneration have only a vague awareness of the technology of CHP, or how CHP might fit into a future when the use of fossil fuel is restricted to the transport sector. We have to remember that proponents of CHP, like their often criticised colleagues in the fossil power plant and nuclear sectors, are just men and women, like ourselves, who have to provide for their families, and will put the best gloss on what their technology is supposed to provide.

Accordingly, what this report aims to do is to outline the technology of CHP, to highlight what are its possibilities and to indicate what are its shortcomings. The paper will also endeavour to look at the more distant future when the supplies of gas and coal begin to decline. What the report will not do in any detail, except in Section 2, is to "moan" about the financial problems currently faced by CHP. Nevertheless the writer is at one with the "moaners". It is quite clear that even in those countries that have had a strong commitment to cogeneration, the belief that "liberalisation" of the energy market, and the encouragement of competition, is the best way of reducing energy costs has had a pernicious affect on CHP. But liberalisation has had a bad effect all the way through the energy field. The emphasis on short term financial gains, and reducing prices to consumers, undermines the prospects for any energy technology where profitability is only achieved after many years of operation.

There is yet another reason for writing this paper. In common with all other suppliers of electricity, the picture that is given by the CHP sector is one in which any shortcomings of the method of generating power are either overlooked or is assumed to be made good by something else. To give a non-CHP example, nuclear power generation has to be base load for economic and technical reasons. Hence the day-to-night variation in demand is made good by the two shifting of steam and CCGT plants, or by making use of hydro. Another common fault in discussing CHP and other forms of power generation is to ignore or discount how the future may be different from the present. Although it is now historical interest, many of the problems of the coal fired power plant sector came about because they did not see the significance of the development of the CCGT. There is the converse to this, of course, in which future changes are overstated, which leads to a belief that things are going to get easier for particular methods of generating power. **Quite possibly for all the excitement that is now going on about climate change and the need to sequester CO_2, very little will happen.** Either we will go on building power plants in the same old way and any reductions in CO_2 will come from the increasing use of genuinely renewable sources. Hence one aim of the paper is point out the hidden assumptions which are made when discussing the advantages and prospects for CHP.

2. Market Forces and CHP

CHP has always had a difficult time in the UK, the proportion of electricity coming from cogeneration actually peaked in the UK in the 1950's. It now struggles to meet the UK Government target of 10%, with almost as much capacity being taken off the market as new equipment is being commissioned. The situation is not too dissimilar in the rest of Europe. CHP is under threat, largely as a result of market forces. Denmark, which has done more than any other country to utilise cogeneration as an energy saving measure, envisages little growth in this area.

For market forces, we can read the requirement for the electricity supply industry to provide the cheapest possible power, and the highest possible return on investment over the near term future. In this way electricity regulators, acting on behalf of governments, ensure that prices are kept low enough to prevent these becoming a serious political issue. Furthermore, the concern about a quick return on investment, ensures that shareholders can look forward to near term profits.

Neither of these policy drivers is helpful to cogeneration, particularly where the cogeneration scheme is of the district heating type. There will be a lengthy process in getting the agreement from heat users to obtain their heat from a cogeneration system. Then there is an even longer process in installing the pipework, valves. heat exchangers (or new high pressure radiators) and heat meters, before heat can be transmitted. This implies a very long period before an investor can see a return, or before greater efficiency leads to a reduction in energy prices. Even where cogeneration schemes are of the local type, in which the electricity is generated from an internal combustion engine or gas turbine, there will be financial problems. Since gas is the only sensible fuel in most cases, this will be supplied at a domestic or industrial rate, and tends to be at a higher price than that offered to CCGT plant operators. This is more reasonably than it sounds. Local users of gas have to use the gas distribution systems which costs a lot to install and maintain More importantly, the capital cost of a local generating system, using internal combustion engines will be two to three times higher than that of centralised power plant. Maintenance costs are higher, and if the equipment becomes unserviceable, the need to buy in stand-by power will be prohibitive.

Essentially there is no “technological” solution to this problem. It is in the hands of our political masters. The Danes, and to a lesser extent the Dutch, have enacted legislation which used to ensure that priority was always given to a cogeneration scheme in the provision of electricity. The point has now been reached in Denmark when coal, gas or biomass is available as fuel, the first thought is to try to use it in a cogeneration scheme. The situation is not quite so clear in the Netherlands where cheap power can be imported from Germany and other countries. Here CHP is starting find life difficult.

3. How Much Power ?

The issue of how CHP integrates with the grid will be dealt with in a later section, but it seems helpful at this stage to put some numbers on the table. Peak demand in the UK is just under 60 GW, or about 1 kW per head of population. The figure is slightly misleading since it includes the power needed for industry. In terms of peak power requirements for a typical household, the peak demand can easily reach 15 kW. Average power needs, in contrast, are in the 0.3-0.5 kW range (300-500 watts).This is one reason why house by house micro CHP has to rely on importing power to meet the peaks. Fortunately, the peak demand of large groups of houses is much less. The writer has been told that local transformers are rated for a peak of two kilowatts for each household, which ties in, more or less, with the 1 kW per head of population quoted earlier.

It follows that the ideal, larger sized CHP, supplying a city , but not industry or big business developments, would be offering **a peak output** of about 500-700 watts per head of population. During low periods it would need to be operating reasonably efficiently giving outputs in the 50-100 watts per head region. This is quite a range to ask for from one unit, and in practice a number of lower output units would need to be used, this giving higher security and the ability to take equipment off line for maintenance. But more CHP sets adds to costs.

4. The Declining Need for Space Heating and Some Consequences

Some accounts of CHP neglect this issue altogether, or if there was a reference to the subject it would be tucked away in a subsection. As a result of **EU Directives** all new buildings in Europe, and this includes the UK will have to be built to much higher insulation standards. The ultimate is the zero emissions house. In the UK, the aim is to get heat demand down to 1 kW (9 MWh/annum). For older houses in the UK, which are the worst in Northern Europe, efforts are being made to insulate, and bring down fuel use from the average of 25 MWh/annum to a more reasonable figure of say 15 MWh/annum. Electricity use is also starting to fall, but at the present time is around 5 MWh/annum for a three bed roomed UK house Hence in terms of the ratio of electricity to heat, the target figure for a low energy house will be about 1:2, implying an the need for an electricity efficiency of about 30%. For an older house with improved insulation the ratio is about 1:3, implying an electrical efficiency requirement of about 25%.

These efficiency values do not seem to be challenging, but they are average values, taken over a year. In reality, heat demand increases quite steeply in the winter and virtually disappears in the summer. Improved house insulation will increase the summer low period from two months of the year to about 3-4 months in the older, but insulated house, and perhaps as much as six months in new-build construction. It will mean that for much of the year CHP sets will be producing nothing but electricity, and this in a relatively inefficient manner.

To put matters into perspective, by 2020, we could expect to see CCGT plants operating at an electrical efficiency of 60%. Medium sized CHP internal combustions engines will be averaging 40%. It follows that for much of the extended summer period, the domestic users obtaining their energy from a CHP generator will be using half as much again as the energy that they would have used if getting it from a CCGT.

Let us see what happened if we compare the relative energy savings in **an insulated older house** in which the electricity is supplied from a CCGT, all the year round, and where the house is heated by gas, with one in which the power and heat come from an efficient internal combustion engine.

In working out the energy savings, we have appreciate that because of the increased heat demand in the "wintertime" period, some of the electricity from the internal combustion engine will have to be used for heating, since the heat from the IC engine will not be adequate. Hence during the "wintertime" the electrical efficiency of the IC engine falls to around 20% .In this case the wintertime period, last for 8 months or 0.67 of a year

For the Separate Electricity and Gas for an Old but Insulated House.

In winter electricity is 5 MWh x 0.67 = 3.35 MWh
Fuel used in CCGT @ 60% efficiency =3.35/0.6 =5.58 MWh
In winter gas use is 15 MWh =15 MWh

In summer electricity is 5 MWh x 0.33 =1.65 MWh
Fuel used in CCGT @ 60% efficiency =1.65/0.6 = 23.33 MWh

Total Fuel Used: 23.33 MWh

For CHP for an Old but Insulated House

In winter electricity is 5 MWh x 0.67 = 3.35 MWh
Fuel used in IC engine to produce heat is 15 MWh = 15 MWh
Therefore total fuel use in wintertime is 3.35+15 MWh = 18.35 MWh

In summer electricity is 5 MWh x 0.33 = 1.65 MWh
Fuel used in IC engine @ 40% efficiency = 1.65/0.4 = 4.12 MWh

Total Fuel Used: 22.55 MWh

If we now compare the **low energy house** on the same basis in which there is no heat requirement for six months (0.5 year)

For the Separate Electricity and Gas in a New Build House.

In winter electricity is 5 MWh x 0.5 = 2.5 MWh
Fuel used in CCGT @ 60% efficiency = 2.5/0.6 = 4.17 MWh
In winter gas use is 9 MWh = 9.00 MWh

In summer electricity is 5 MWh x 0.5 = 2.5 MWh
Fuel used in CCGT @ 60% efficiency = 2.5/0.6 = 4.17 MWh

Total Fuel Used: 17.34 MWh

For CHP for a New Build House

In winter electricity is 5 MWh x 0.5 = 2.5 MWh
Fuel used in IC engine to produce heat is 9 MWh = 9 MWh
Therefore total fuel use in wintertime is 2.5+ 9 MWh = 11.5 MWh

In summer electricity is 5 MWh x 0.5 = 2.5 MWh
Fuel used in IC engine @ 40% efficiency = 2.5/0.4 = 6.25 MWh

Total Fuel Used = 17. 75 MWh

Table 1 summarises these rather rudimentary calculations. It will be seen that the annual energy savings that are made are marginal. **And in the case of the newly built and highly insulated house the use of CHP actually results in energy being wasted.** The savings that are made in the wintertime are offset by having to run a relatively inefficient CHP unit in summer. For CHP to be of any use, it would have to be shut down for much of the year, with households and small businesses drawing their power from centralised power plants.

Table 1: Summary of Fuel Use and Energy Savings in Highly Insulated Housing

Type of House	Energy Supply	Annual Fuel Use	CHP Fuel Saving
Insulated Older House	Separate Gas and Power	23.33 MWh	**plus 0.78 MWh**
	CHP Only	22.55 MWh	
New Build Construction	Separate Gas and Power	17.34 MWh	**minus 0.41 MWh**
	CHP Only	17.75 MWh	

As noted, these calculations are very simplistic and neglect many factors. Transmission losses from centralised power systems have not been counted. These can be up to 10%, hence a CCGT plant works at an efficiency of 54% rather than 60%. On the other hand heat losses through pipework from a CHP unit have also been neglected, and if a CHP unit has to send its electricity through the local network, it will encounter similar losses to that of centralised power plants (the losses in the high voltage grid are only 1-2%.....most losses occur in the local system and are in the 6-8% range)

Exercises, such as this, exemplify the loopholes in the arguments put forward by protagonists for CHP. Comparisons are often made with coal fuelled steam plants in which the efficiency is set at 35%, and furthermore, the hidden assumption is that the CHP system operates throughout the year. **Nether of these statements is really correct at the present time, and the development of improved standards of insulation and more efficient centralised plants will make such arguments even more misleading.**

5. Efficiencies of Real CHP Power Units

The efficiency figure of 40% for the generation of electricity, which was given in the previous section for a locally based CHP unit, may be perceived as being low, but it is actually at the top end of what might be expected. Until a very efficient fuel cell is developed there is no prospect of a CHP unit getting to figures much higher than this.

The other efficiency figure, which is important, is what might be described as the total or CHP efficiency, which is the electrical energy plus “useful heat” energy, all divided by the energy of the fuel input. The EU Cogeneration Directive gives some target values for CHP efficiency, in which, providing these values are attained, all the electricity that is generated can be ascribed to be of the “high efficiency type”. In such a case, all of the electricity may be entitled to obtain, what is, in effect, a subsidy.

The actual target values depend on the type of equipment. Systems such as CCGT and extracted steam turbines, which can be switched over to a non-CHP, mode are given a harder target of 80% CHP efficiency. Other types, in which the generation of electricity is inherently less efficient, are given a target of 75%. The prime movers in this group include:

- **Back Pressure Steam Turbine**
- **Larger Type Simple Cycle Gas Turbine**
- **Internal Combustion Engine**
- **Micro Gas Turbine (usually of a recuperative type)**
- **Higher Output Stirling Engines**
- **Fuel Cells**

Neither of these target figures is close to 100%, but in fact 100% will never be attainable, except, perhaps, for some types of fuel cells operating on hydrogen. The inability is a result of the need to release the exhaust or flue gases to the atmosphere at above 100°C, so that the flue gases will rise and dissipate into the atmosphere. Between 5-15% of the heat in the fuel is lost as a result, gas turbine based systems are worst in this respect ; to keep the operating temperatures to a level acceptable to the turbine alloys, a very large amount of excess air has to be used in the combustion process. This “extra air” carries off heat. Micro gas turbines, which invariable use recuperators to reduce fuel consumption to improve electrical efficiency are about the worst, since the level of excess air is even higher than in a conventional gas turbine. CHP efficiencies are typically in the 70-80% region.

5.1 Internal Combustion Engines

Internal combustion or IC engines, as they are often called, are basically a refined version of the engines we have in our cars, but running on natural gas rather than petrol. Car engines have actually been used in CHP systems, with power outputs in the 50 kW region. Although it seems a very good idea to utilise a relatively cheap mass production unit, experience has not been brilliant. A modern car engine might be expected to last for at least 200000 km, but this would only amount to less than a years operation, with servicing having to be done every few weeks. There are also additional features, such as the need to run at a constant speed, despite any changes in load, which add to complexity. Control of NOx emissions adds to costs.

Fig 2: A Caterpillar CHP Engine of about 42% Efficiency

The more conventional approach is to build a big, heavy sturdy machine in which the power output is in the 250 kW to 5 MW range, and running at a constant 3000 rpm (3600 rpm in the USA). The efficiency of such units is essentially determined by the compression ratio. The higher the better, but there comes a point when the engine begins to “knock”.

Knocking is a very damaging process, in which, because of the mixture of gas and air in the engine becoming overheated, it effectively explodes during the combustion process. The risk of knocking increases with compression ratio, and although we now know how to minimise the propensity to knock at high ratio, this is an engineering barrier, which has been with us for almost 100 years. More recently there has been a quiet revolution in engine design. By changing the "valve timings" on engines, based on the Miller/Atkinson Cycles, rather than the Otto or Four Stroke Cycle, the propensity to knock has been minimised. The best IC engines, running on natural gas, now offer efficiencies in the 38-44 % range. Figure 2 shows a typical example.

There is one bonus that does result from the way the IC engine operates. The exhaust gas temperature will be in the 700°C region in a non-supercharged engine. Even when turbocharged it could be as high as 500°C. About half waste heat from the engine comes in this high temperature form. This can be very useful where the CHP system incorporates an air conditioning units, where high grade heat is required to operate absorption type cooling systems. More commonly, the exhaust gases pass through a heat exchanger, the reverse side of which carries the water that is used for space heating, or in some cases production of low pressure steam. The remaining heat from the jacket cooling water and lubricating oil is below 100°C and can only be utilised for space heating

5.2 Diesel Engine

The diesel engine is a close cousin of the IC engine, but overcomes the compression ratio limit and knocking problem in a unique way. By injecting **liquid fuel**, as droplets, at the end of the compression stroke, which immediately start to burn, there is no mixture of air and gas within the cylinder that has the potential to explode. The ability to run at compression ratios is the 13-17 ranges, endows the diesel with efficiencies in the 42 to 48% range for the type of unit used in CHP systems. Such engines are usually turbocharged, and the result is that the exhaust temperatures are below 450°C. The higher electrical efficiency will result, of course, in less heat being available, but overall the power plus heat, or "CHP" efficiency, will be similar to natural gas IC engines, at 90-95%.

Electricity is far more valuable than heat, in kilowatt hour terms, the price ratio is about 3-4 to 1, hence even the relatively small increase in electrical efficiency from diesels compared to IC engines is valuable. The big drawback of diesels is that thy will only operate on liquid fuels, and until very recently this has meant diesel. But as is now well known, automotive diesels will run on used "chip oil", so providing that the price is right and the availability is good, we could see some CHP installations being of the **bio-diesel engine type**. In practice, biofuels are likely to be too prohibitive for continuous running, except for niche applications, such as in rural areas. The best prospects for diesels would be for standby power, coming into action when electricity from wind or solar fails. But these would not be CHP machines

5.3 Gas Turbines

The gas turbines used in CHP units are variants of the turbojet and turbo prop engines used in aircraft. There is usually some de-rating in power output; and would be similar to an engine operating under cruise conditions, rather than those of takeoff. Gas turbine, derived from aircraft units, will be offering a relatively large power output. Typically this will be in the 5-60 MW range, which is often too high for most CHP schemes. Unit costs are probably high, reflecting those in the aerospace industry. The positive aspect of such units is that engine reliability is very good, and times between maintenance are extended.

The higher output engines will offer electrical efficiencies of just over 40%, but a more typical figure is likely to be closer to 30%. The main reason for this is that gas turbines suffer from strong “size effects”; aerodynamic perfection falls as compressor and turbine blades become smaller.

Related to the aerodynamic issues, is the poor part load performance of gas turbines, with electrical efficiency dropping away as the output falls. Variable incident inlet guide vanes on the compressor, will help, but basically a gas turbine is a machine that wants to work at above 85% of its design rating. It follows that in a typical district heating scheme, where there are big variations during a 24 hour period, gas turbines are not necessarily the optimum choice. One way of overcoming this is to chose a number of lower out put machines instead of one or two big ones, although this can be more costly.

As mentioned earlier, the CHP efficiencies of even the larger gas turbines are likely to be mediocre, and not much above 85%. Gas turbine installations suffer from other intrinsic problems. Although there is no vibration, intake and exhaust noise will call for bulky sound proofing and careful location, away from domestic housing. The burners require the fuel gas to be at high pressure, 20-30 bar, which will need a fuel gas compressor. And finally, because the power output from gas turbines suffer from pressure drop effects, the heat exchangers, needed to pick up the heat from a gas turbine exhaust have to be big to minimise this effect.

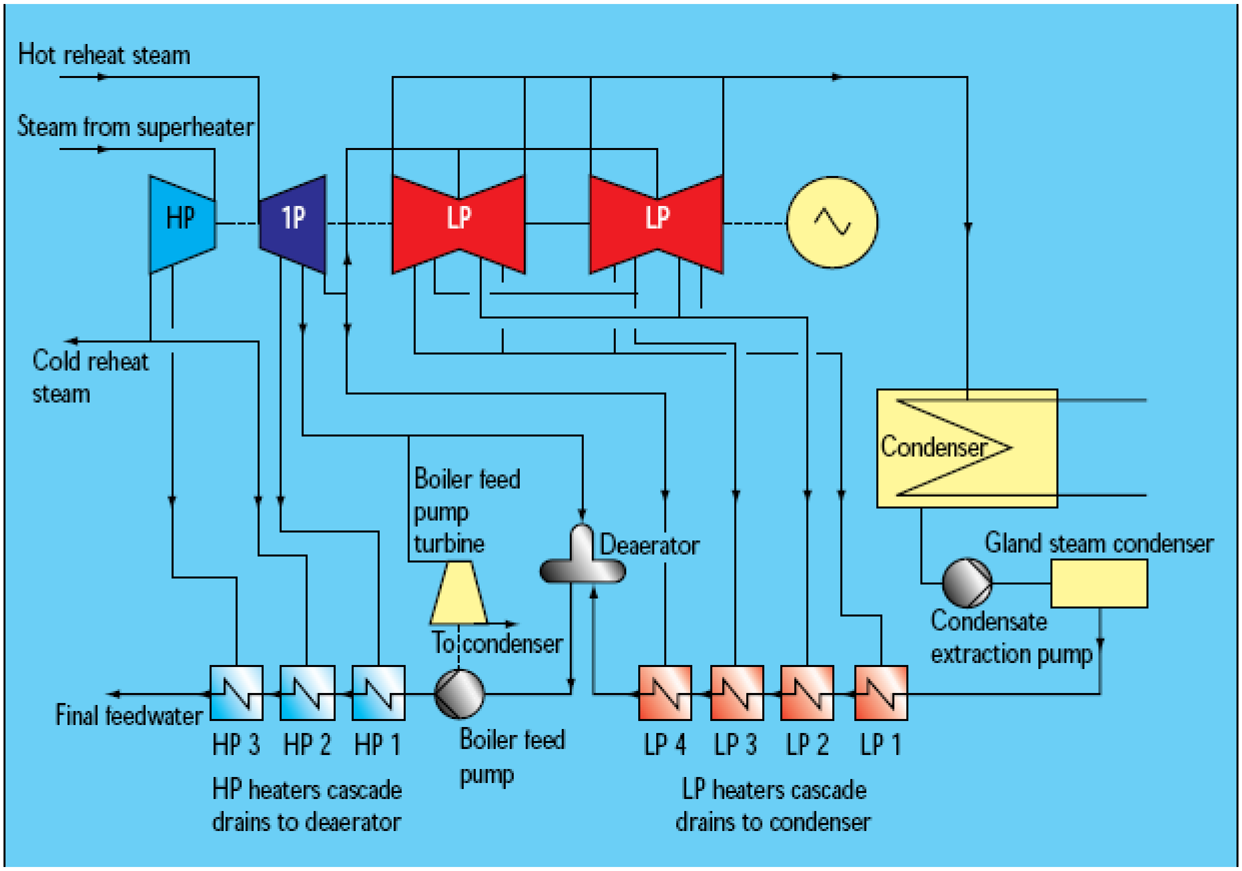
5.4 Coal Fired Steam Plant with Cogeneration

We now come to bigger installations, among which is steam plant. The practical lower limit is about ten megawatts, but the biggest installations are about the size of a medium sized power stations, of a two to three hundred megawatts output.

A steam turbine plant requires a boiler to provide the steam, heated by coal, oil or natural gas. After passing through the turbine, the steam is condensed, and the water is sent back to the boiler to produce more steam. In practice the circulation of steam and water is far more complex than this. A key development in the improvement of electrical efficiency was the extraction of a portion of the steam from the turbines which is used to preheat the water before it reaches the boiler. Obviously power is reduced , but even with one extraction point, efficiency is increased by 2-3%. Today, as many as eight extraction points will be used on a big power plant, it being referred to as **(boiler) feed preheating.** Figure 3 shows the layout for a conventional steam power plant. In a CHP system, most of the LP feed heaters (orange blocks) would be shut off with the steam being used to heat the water in a district heating system.

The extraction technique is also used on some types of CHP systems. Here, instead of the low pressure extracted steam being used to preheat boiler water, it is passed through a heat exchanger to give heat to the water in the CHP system. Quite a small amount of steam can provide a great deal of heat, with only a small loss in electrical output. Furthermore, one big advantage of extracted steam turbine CHP, is that, if heat is not needed, the extraction valves are closed and all the steam is used to produce electricity.

Figure 3: Steam and Feed Heating Systems in a Conventional Power Plant



The other approach, in using steam for CHP, is to use the back pressure type of steam turbine. Here, all the steam passes through the turbine, apart from that used for feed preheating. The difference between a back pressure turbine and one of the conventional type, is that with the conventional type, the steam is condensed after it has reached a very low temperature and pressure. Typical values would be 35°C, 0.05 bar pressure (i.e. near vacuum). This is great for maximising power, but useless for heating, since the cooling water, after it leaves the power station, will be in the 15-30°C range .

The back pressure turbine, in contrast, takes the all the steam from the back end of a steam turbine, at a pressure of about 1 bar and 100°C. The steam passes over the CHP system heat exchanger, which acts as a high temperature condenser. The condensed steam, in the form of hot water at about 80-90°C, is then pumped back to the boiler. The water going into the district heating systems will range in temperature from 70° to about 120°C, depending on the local requirements But many back pressure steam turbine units can only operate in the true CHP mode, since the heat exchanger condenser is designed for operation at about 100°C. The power to heat ratio of such units is more or less fixed.

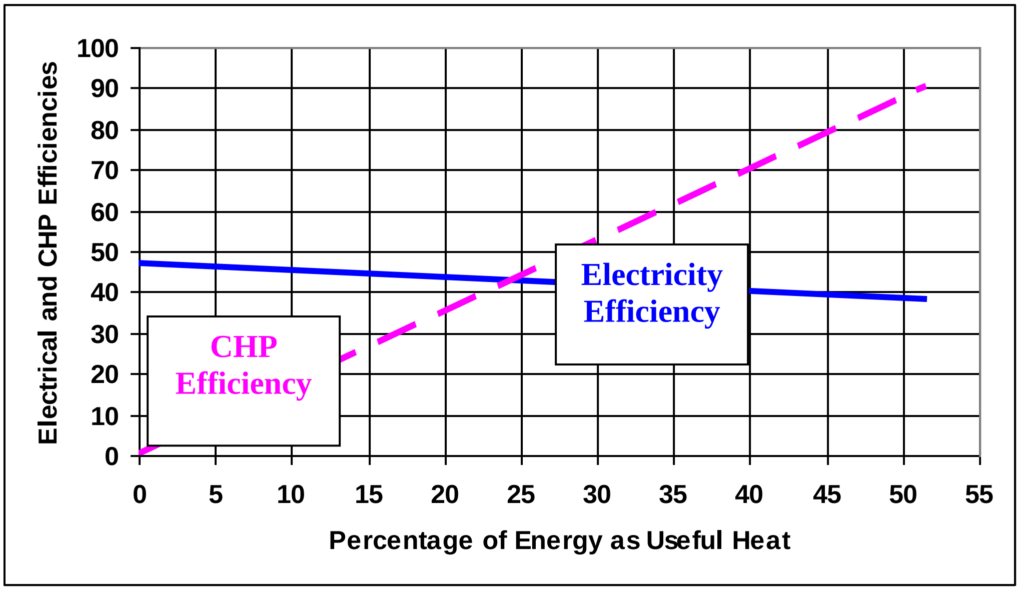
Fig 4: The Nordjyllandsværket Coal Fired CHP Power Plant in Denmark

A well designed extractive steam turbine plant is far more flexible. The Nordjyllandsværket unit in Denmark is able to operate with a very large degree of extraction, so that when in the full CHP mode, over 90% of the fuel energy is converted into electricity and useful heat, as shown in Figure 5. At times when heat is not required, all the steam passes through the turbines, the electrical efficiency reaching 47.2%. It will be apparent from the figure, that for every percentage drop in electrical efficiency, five percent of the fuel energy is produced as useful heat. In other words, a 10 megawatt drop in power output produces 50 megawatts of heat. The relative prices charged by the power plant owner will need to reflect this fact, hence, in principle, heat costs will be 20% of the electricity price. In practice the costs of heat will not be so low, because of the need to cover the extra costs of extraction systems, heat exchangers and pipework needed for a CHP system (this excludes the distribution pipe work).

When operating in the full CHP mode, the electrical efficiency drops to 38.4%. It will be noted that this is about the same level as a typical IC engine or higher output simple cycle gas turbine. The advantage that a plant like Nordjyllandsværket is that its fuel is coal rather than expensive gas.

One point has to be made about the Nordjyllandsværket example. The cooling water for the condensers in Denmark is cold North Sea seawater at 6°C. This permits the condenser to run at a much higher vacuum than in the rest of Europe, and results in the electrical efficiencies being about 1.5-2.0% higher than would be the case where the cooling water comes from rivers and estuaries.

Figure 5 : Variation of Electrical and CHP Efficiencies with Heat Output at Nordjyllandsværket



5.5 CCGT with Cogeneration

The CCGT (Combined Cycle Gas Turbine) is the most efficient method we possess for converting the fuel energy in gas, into electrical energy. At the present time efficiencies have levelled out at just under 60%. The CCGT, consists of a gas turbine which produces about two thirds of the power. The waste heat in the exhaust system from the gas turbine is used to raise steam which powers a set of steam turbines, producing the remaining third. It is only the steam system which can be used for cogeneration duties, so a CCGT is not so good as steam plant for a CHP. This fact is well recognised and most industrial scale CCGTs, utilise an ancillary burner, situated after the gas turbine exhaust, which is used to raise extra process steam. In such cases this is not true cogeneration. Figure 6 shows a non-CHP CCGT at Peterborough.

The heat exchangers for evaporating water and superheating the steam in a CCGT are referred to as the HRSG (Heat Recovery Steam Generators) and are situated in exhaust duct of the gas turbine. For various reasons steam has to be raised at two or more different pressures, typically 60-90 bar and 5-10 bar. The high pressure steam is fed to high pressure turbines, and the exhaust steam from the HP turbine is used to join up with low pressure steam before it enters the low pressure turbine. See Figure 7

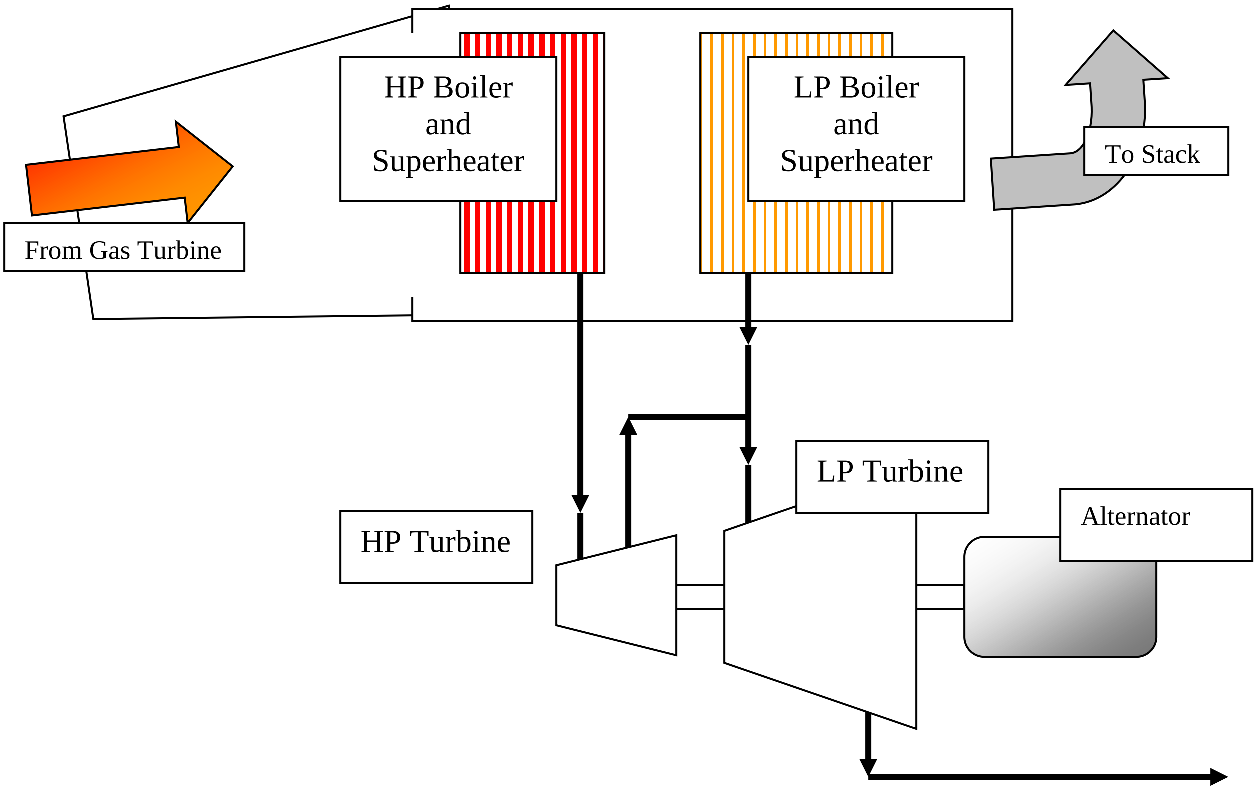
In a conventional CCGT the exhaust from the low pressure turbine would be at about 0.5-0.7 bar, but in cogeneration mode some of the steam could be extracted from the LP turbine for district heating. Because the steam section of the plant provides only a relatively small amount of power, and because the stack losses in CCGT are high, the amount of useful heat that can be obtained from a CCGT is limited. If the steam turbine units were shut down completely, on a typical plant only 50-55% of the heat energy in the fuel would be available for district heating purposes. But electrical efficiency would fall to around 37%.

Figure 6: Two HRSG Units at Peterborough CCGT

More realistically, if three quarters of the energy in the steam section of the plant were used for district heating, one might expect the electrical efficiency to fall from 58 to 43%. The amount of energy available in the form of useful heat would be 26% of the fuel input, giving a CHP efficiency of 82%, or just over the EU target of 80%. In this case, the exchange ratio, in which the drop in electrical efficiency is compensated by the useful heat, is not so good as in the steam plant. For each 1 MW drop in electrical output, the amount of heat increases by only 2.5 MW. If we assume that the cost of power from such a plant was 3p/kWh (£30/MWh), the cost of heat would need to be at least 1.2 p/kWh, which would probably not be competitive with gas in the UK at the time of writing (Oct 2006).

Indeed, it can be argued that a CCGT based cogeneration plant is an expensive way of turning the fuel energy in gas into low grade heat. The most appropriate market for CCGT cogeneration would appear to be that of the process industry sector, where there is a need for steam. Here because of the “air preheat” resulting from the use of the gas turbine exhaust, a substantial energy saving can be made.

Figure 7 Schematic of HP and LP Steam Systems in HRSG



5.6 Nuclear Cogeneration

There are some places in Eastern Europe where a small amount of useful heat is used for local heating of nearby buildings, but the idea of using nuclear energy for cogeneration seems impractical. In Sweden, which has extensive district heating and <u>was</u> very reliant on nuclear power, **nuclear generated electricity was used to supply much of the space heating using hot water**. That is, the hot water network was used as a gigantic storage heater.

A modern nuclear power plant of the PWR (Pressurised Water Reactor) type generates about 2 GW of electricity, but in converting only 32% of the heat from the nuclear reactions into electricity, is not very efficient. Steam temperatures, at about 260°C, are just too low . If modified to produce cogeneration heat, output would probably drop to about 1-1.5 GW, and the amount of useful heat is likely to be in the 2-3 GW range. A two metre diameter pipe would be required to transmit this amount of heat, assuming a temperature differential of about 70°C between outflow and return. This is somewhat larger than the 42 inch (1.07 metres) pipes used for gas transmission. Cogeneration pipes do, however, have to be insulated and possibly have to be positioned in a concrete trench. Heat from the pipe would eventually kill off vegetation, leaving a deep scar across the landscape. Furthermore, unlike gas transmission, there has to be a return pipe back to the reactor.

The other issue is the need for additional connecting pipes to give redundancy. In effect a **National Hot Water Grid** would have to be established, so that when a nuclear station goes off line, heat continues to be available from another reactor. Clearly the requirement to dig massive and deep trenches through miles of the English landscape, all of this being associated with the magic word "nuclear", will result in a major planning headache.

5.7 Micro CHP

Two separate forms of micro CHP have been promoted. The higher output, up to about 100 kW, relies on modified car engines or small recuperative gas turbines. The car engine approach suffers from the need for high maintenance. The micro gas turbine, although using a recuperator, has quite a low electrical efficiency. And as noted earlier, the CHP efficiency tends to be low because of the large excess air required by the unit. Since these units would be intended for small business or apartment blocks, electrical efficiency is fairly important. 30% at both high and low loads would be a sensible, but so far unrealised target.

The other possibility may be termed sub-micro CHP, in which the power output is around 1 kW, enough for a typical house. Ideally, the engine would be an integral past of a gas boiler, and light enough to be attached onto a wall. Because, in principle, all of the heat, apart from the exhaust gases, enters the household, high electrical efficiency is not too important in itself. That is, if the electrical efficiency was zero the unit would behave just like an ordinary gas boiler in terms of it energy efficiency. However, if the true electrical efficiency falls below 20%, the amount of heat produced for each unit of power becomes excessive, and in well insulated houses would be an embarrassment.

6. More Advanced CCGTs : Threat or Salvation?

The CCGT is so cheap to build and so efficient to operate, that for the past thirty years it has virtually killed off steam plant construction in Europe. The main exceptions have been Denmark, which has used its natural gas for local CHP systems and Germany, where because of the lignite reserves, steam plants have been built using this as a fuel. The efficiency and low capital cost of CCGT have also been a thorn in the side of cogeneration, although this only became apparent when market forces were allowed to rip. Even the "better use energy" claims of the CHP sector start to look weak, when set against the best CCGTs.

For the present time, the increases in efficiency of CCGTs have levelled off at just under 60% .This compares with the first really commercial units of the early eighties that were giving about 42-44%. What of the future? It needs to be recognised that CCGTs, at the present time, are basically a very simple concept. They use an enlarged version of an aircraft gas turbine as the main prime mover, which on a number of counts is not the best choice. There are more sophisticated land based gas turbines, in which, by tweaking the thermodynamics, and by improving the turbine and hot section cooling techniques, are offering machines which have a significant increase in thermal efficiency. The various concept include:

- **Reheat or two stage combustion in the turbines**
- **Intercooling of the compressor**
- **Steam cooled turbine blades**
- **Steam cooled hot section**
- **Cooling of compressor air used for disc and bearing cooling**

The gas turbine manufacturers have tended to apply these techniques on an individual basis. For example, steam cooled blades are incorporated in to the latest GE 701 and 901 machines, and Alstom use reheat in their GT 24 and 26 machines. However there is no reason why these ideas should not all be incorporated into one machine. If this were so CCGT, electrical efficiency would rise to the 70-75% region. Gas turbine efficiency in such a machine would be in the region of 50%.

Efficiencies at this level would seem to kill off any prospects for CHP. But is there any upside for cogeneration? It was pointed out earlier that the Achilles heal of current designs of CCGT is the excessive stack losses that are a result of having to use a huge amount of excess air to control combustion temperatures cool critical components. Fortunately, all of the innovations listed above will reduce the excess air requirement. Perhaps as much as 95% of the fuel would be used for energy production instead of the 80-90% of today's units. The direct result is that it should be possible to maintain steam plant output, despite the fact that more energy in the fuel is taken up by the gas turbine. In principal, therefore, providing it is perceived to be economic to sell heat at a fairly high price, an advanced CCGT, when operating in cogeneration mode could supply 55-60% of the fuel energy as electricity, and 40-35% as useful heat. A unit such as this could go over to all power generation in the summer, running at up to 75% electrical efficiency, providing that natural gas was available.

7. Reliance on the Grid

One of the constant moans by CHP operators is the competition from centralised power stations. In practice very few cogeneration schemes are able to operate without a continuous connection to the grid. The grid is available for peak power requirements, or when units are shut down for overhaul.

It is possible to run independently of the grid. The author used to work on a gas making plant which had a set of 900 kW diesel-generators that could operate in parallel with the grid or work offline. The issue was when switching back on, accurate matching of generator speed with grid frequency was needed. On this plant, however, the power requirements were well controlled ; there was no "post- football cup match" power surge, when the whole of the UK decides to make a pot of tea. The ability to run through a power surge such as this is one reason, why the connection to the grid is needed.

The question for CHP is what happens if centralised power disappears? In some countries, if they disavow nuclear, there will be massive reliance on renewable energy.. In the UK we will be reliant on wind, solar, wave or tidal power, which are characterised by their "intermittency", and will need back up by more controllable sources. It follows that cogeneration units will have to become the most vital part of the grid, always supplying enough power to help maintain grid frequency. To be effective, cogeneration capacity would have to be of the order of 40-50 GW or about five times the current level.

8. Fuel Supplies and Renewable Heat

There is little doubt that natural gas is the fuel of choice for cogeneration. Unfortunately supplies of natural gas in Europe are in decline. This is a critical issue for the UK, which has switched from a coal based to a gas based economy within the last fifty years. Despite the long-forecast need to import over 90% of the UK's natural gas requirement, by 2020, the only power stations that are currently being built are conventional CCGTs. Even now, because 30% of our electricity is produced from CCGTs, we are having to import the equivalent of 50 millions tonnes a year in coal equivalent of gas. That is we are just about self sufficient in using gas for heating, in a sense all of the imports are being used to generate electricity.

The "real coal" situation is similar. Two thirds of UK coal is imported, which along with indigenous supplies, accounts for about one third of the power generated in this country. By 2020 the chances are that all the coal we have to use will need to be imported.

It is arguable, whether given these facts it is worth making a large investment in CHP in the UK, per se, since all it does is perpetuate our reliance on fossil energy. Somewhat surprisingly, there is a case, however for the establishment of district heating since this can make use of **renewable heat**, or heat which is generated from the combustion of biomass and direct resistance heating using power from wind and solar energy. Systems such as this would need to incorporate hot water storage, of the type used in Denmark.

Biomass and the combustion of waste can make a contribution in the UK, but it seems unlikely that this will exceed 5 GW. Most biomass can only be used to fuel steam plant, the electrical efficiency of which is likely to be lower than what is obtainable from coal; plants, although CHP efficiencies should be reasonably high. Other countries in Europe, where the population density is not so high, namely Denmark and Austria, are already making good use of biomass for district heating. The prospects of converting some of these to cogeneration schemes are good.

The Danes, as usual, are thinking ahead, and see a decline in both gas and coal based CHP. The plant at **Avedore, shown at the start of this paper**, consists of two separate furnaces for steam production, one using coal, the other using biomass. In this manner it is possible to obtain a good electrical efficiency.

More indirect forms of renewable heat can also be envisaged. **Heat pumps seem a viable option. These would be powered by renewable electricity, using as a source of low grade heat, the water in district heating systems.** This should be more economic than ground based heat pumps. Hydrogen produced by electrolysis is another option, but a surprising fact is that volume-for-volume, it is possible to store about ten times more energy in hot water than hydrogen. However we will see hydrogen being generated as a feedstock for the production of ammonia, biochemicals, biofuels, and in steel making, so it seem sensible to try to make use of it in CHP, wherever practical.

Over on the Continent, where there has already been a substantial investment in cogeneration and district heating, there are better prospects for the continuation of cogeneration, particularly if this is based on coal, even when imported. As the Danes have shown, medium sized power plants offering respectable electrical and CHP efficiencies are quite practical. There is no reason why, given an existing district heating network, each big town should not have its own power station. Such units could be of the carbon capture type. The electrical efficiency in this mode would fall to about 26-29%, and the CHP efficiency to just over 80%.

For some countries, such as the Netherlands, which has a lot of cogeneration, IGCC (coal gasification plant) producing substitute natural gas (SNG) and electricity along with limited carbon capture would be the most efficient and economic use of imported coal. The main product of the plant would be SNG. This would be burnt in a highly efficient CCGT plant either on the same site, or somewhere else in the Netherlands. Obviously it could also be of the cogeneration type and would have the advantages described in Section 6.

For the UK, a more sensible option in the use of such a plant would be for it to be producing SNG, most of which would be used to supplement our declining gas reserves and reduce our need to import natural gas. A limited amount of SNG could be used in cogeneration, but perhaps the best long term option for CHP is the development of 1 kW sized micro household units.

9. District Heating Networks

Large scale centralised cogeneration will require a district heating system similar in scale to the typical distribution network which carries natural gas around towns and cities. Installing a heat network would be a massive undertaking in existing built up areas, and the cogeneration fraternity are remarkably silent on the costs of this. An estimate known to the author is of the order of £1000-1500 a metre, but this probably applies to larger pipes, which are a relatively small part of the system.

A more reasonable estimate can be obtained from recent estimates by Transco for replacement of cast iron and steel gas mains and pipework by polyethylene. This works out to about £130 to £150/metre. Unfortunately, there is no breakdown about the relative costs of gas mains versus small diameter pipes. What is certain is that heat mains will be more expensive. In the Transco case, the gas industry is replacing old for new, with the ground in which the pipes lie belonging to the company. A system of heat pipes would have to find space amongst the existing mass of electric cabling, water and sewer mains, and gas pipes. And given that heat pipes have to be kept away from cabling which might degrade, because of the heat that does leak out of even insulated cabling, it might be sensible to double the Transco figure. Assuming that we had a one-to-one replacement of the UK natural gas system by a heat network, the cost would be in the region of 50 billion pounds. Surely if this kind of money was available it would be better to spend it on house insulation and genuinely renewable power?

One response from some in the CHP sector is that the UK should stop the gas mains replacement and begin installing heat networks instead. This is really a cloud cuckoo land idea, but the basis for the argument is that gas will run out. But as been pointed out, when gas runs out there is little future for CHP as we know it. But if the situation got this bad it would be a fairly simple matter to reinforce the local electricity grid by threading new power cables through the now disused gas pipework.

Despite insulation, heat leakage is significant and in many cases if this was included in any assessment, the energy savings that CHP can give, compared to centralised generation of electricity, or by the distribution of gas, would be negligible. In Demark, it is a major issue that the heat system losses are, on average, 18% . **There is indeed, a strong reason for modifying the EU Cogeneration Directive so that it takes into account heat system losses**. The resistance and reactive power loss in the electricity grid and distribution network is considered when energy savings are assessed, thereby making CHP look better than it is, really. So why is the corresponding loss of heat not part of the calculation?

10. Discussion

One would anticipate that this paper will not go down too well with many in the Claverton Group. However, the fact is that not one of the proposed "solutions" to the UK's and Europe's energy problems is as simple and easy as its protagonists like to say. Cogeneration is no different, and in consequence the aim of this paper has been to set out the issues. This paper has been written against the backdrop of the European Cogeneration Directive which came into force in 2004. This is intended to encourage the doubling of CHP in Europe, so as to reduce energy demands. The Directive is also intended to encourage the development of more efficient CHP systems; many of the existing systems, just like, much of Europe's steam plant, have seen better days, and are not really saving energy at all.

There are a few underlying thoughts which run all the way through his document. One is that CCGT plants are very efficient and are and will continue to make life difficult for CHP. Another is that fuel issues need to dominate arguments about the advantages of CHP far more than they do at the present time. **Although this is going to be a very big problem for the UK, the cost of importing coal and gas, it is also going to be a big issue for the rest of Europe**.

The third point which needs to be kept in mind is that each of the European countries has a different "energy history". Denmark has always been short of energy, so it was sympathetic to energy conservation. However, the oil shock of the 1970's forced the Danish Government to move away from oil and encourage the development of CHP at both the large and mediums scale. The UK's economy was founded on the profligate use of cheap coal. We too had our oil shock in the 1970's, but instead of doing anything radical about it, we have burnt up our natural gas reserves , just as we did with coal. Whereas the Danes have the skeleton of a CHP and Distributed Power Network, the UK has a vast network for the supply of natural gas. The sensible thing is for each country to make the best use of the infrastructure it has got.

One issue, emphasised at the start of this paper, is the declining need for heat. Eventually the main requirement will be for hot water for washing people and clothing. This will be a very tight market for CHP, since it will be competing against solar water heating, heat pumps and direct heating of hot water by renewable electricity. **In the UK this could be met by reasonably efficient 1 kW sized micro-generation units, fuelled by SNG or hydrogen.** Electrical efficiency, while producing a reasonable amount of useful heat needs to be around 40%. In this way the best use would be made of a top quality gas distribution network. And 20 million 1 kW fuel cells would go a long way to meeting power demand when wind and solar electricity fails. **Over on the Continent, in towns and cities that have extensive heat mains, these are probably best supplied by efficient CCGTs running off natural gas or SNG.** Here the fact that these more advanced CCGTs are able to produce only a small amount of heat, compared to the electric power, is an undoubted advantage.

Related to this scenario is that the economics of cogeneration will change. CHP will no longer have to compete against centralised power, and low cost gas. In terms of electricity, the main supply will be from renewable energy (or nuclear), which are characterised by their high cost. Bigger CHP operators will get a premium for giving stability to the grid, and all CHP generators will be able to demand " peak time" prices at times when wind and solar sources cease to generate. Of course, the type of equipment which will need to be used will have to change. **Operators who want to generate a limited amount of CHP power, relying on the grid to meet peak demands can expect to go out of business.**

The heat costs will also change. There is no prospect of any of the alternative sources of heat producing hot water as cheaply as does gas at the present time. Even gas will suffer, once consumption falls to the point where virtually no central heating is needed and the only need is for hot water for washing. So the supply of even a limited amount of heat could be profitable.

Overall then, CHP has a future, but it will be a different one to that of today. The supporters of CHP need to begin planning now for a future in which fossil power is short, renewable electricity and heat are expensive, and energy conservation is a top-line commitment. There is probably a ten year breathing space in which to begin to reorient the cogeneration sector. **More of the same is not an option.**

11. Conclusions

An objective, but broadly sympathetic, view has been taken of the future of cogeneration in the UK. Although its current financial difficulties, and uncompetitiveness, appear to have resulted from the market economy, the basis to these difficulties is structural. In terms of electrical efficiency, most of the present equipment does not compete with CCGT power generation, hence electricity costs are high. Heat costs are high, too, because of the expense of heat mains, and because the leakage of heat is quite significant.

The future could be difficult too, with CCGT plants being developed to reach electrical efficiencies in the 70-75% range, natural gas prices going even higher, and energy conservation reducing heat demand to a fraction of that today. Renewable heat is both a challenge and an opportunity. Renewable heat can be supplied from solar heating panels, and by direct resistance heating. Heat pumps are also a possibility. But all of these concepts work better if linked into a district heat network whereby hot water can be stored for reasonably long periods.

The way cogeneration will need to change varies from country-to-country. Only Denmark appears to have a well thought out policy, in which fossil fuels will be phased out and biomass will supply a greater fraction of the fuel required for CHP and pure district heating schemes. For other European countries, which have extensive town based district heating systems there is a strong argument for basing these on advanced CCGT-Cogeneration or coal based steam plant with CHP.

With respect to the UK, the fact is that it possesses one of the world's biggest gas distribution systems, which is being progressively upgraded, cannot be discounted.. Any rational energy policy must try to find a use for it. **Wholesale replacement by a district heat network is out of the question.** What is possible is the limited development of medium scale CHP, part of whose rational, is to support grid from the "intermittency" of wind and solar renewables. But micro CHP or domestic CHP is still a sensible objective for the UK. However, for such units to be viable, electrical efficiency would need to be in the 40% range, and where the heat that is evolved from the CHP "generating set" is at a high enough temperature to be useful. The fuel for such systems would be initially imported natural gas, then SNG from clean coal plants, and finally hydrogen.

;;;

Appendix: Points made by Neil Crumpton of Friends of the Earth

This appendix is a set of good points made by Neil Crumpton of Friends of the Earth, plus my responses in italics

- I think most on Claverton see a balance between community / district CHP heat grids in denser urban areas and next-generation micro-CHP in less dense suburbs. The balance will be a function of technical advances and costs that we cannot be sure about at this moment. So there may be 10 million (10 GW) of mCHP on hand in the suburbs anyway or 15 million (15 GW) covering suburban domestic needs and helping out with peak loads / low offshore wind periods

The basic problem is where is the energy going to come from to power these systems. CHP, by definition implies power production using fossil fuel or nuclear heat?

This is a more complicated question than appears at first sight. On the assumption that Neil is referring to 15 GW of CHP, what is the average electrical output. Is it the same proportion as the UK generation at the present time (60-70% of declared capacity). What happens in the summer time, when the amount of heat drops significantly. How much power will come from CHP?

Unless there is really good energy conservation it is difficult to see how CHP will save much energy. If all of the present power production was of the efficient CCGT type, the UK would be generating around 350-400 TWh from CCGT. The figures postulated in Section 5.5 suggest that the power to heat ratio would be about 1to1.Hence CCGT plus CHP would give 400TWh of useful heat. This would be enough to satisfy the domestic demand but not the service sector or much of industry. On the basis that CCGT plus CHP is just over 80% efficient we would require 1000 TWh of natural gas input, excluding the service sector and business, and own energy industries demand. Even with these exclusion, gas demand would be higher than it is now.

If we restricted CCGTs to about the present level of output, where they supply about one third of UK power, they would only be supplying about 150-180 TWh of heat, which is quite a small fraction of UK heat demands. Because of the reduced electrical efficiency of CCGT-CHP, gas demand would rise to the power generation sector by about 50TWh. So the savings are helpful but not brilliant.

- One scenario should be for zero carbon dioxide emissions by 2040 - so SNG in 10 - 20 million point sources would be out - you mention eventually hydrogen but how much would the hydrogen network to homes cost (e.g. if all further gas network upgrading was specified hydrogen-ready)

If there are zero CO_2 *emissions (or near zero emissions) from power generation or non-transport energy use, this does mean coupling generating plants with "deep" CCS. It will result in increased use of fossil fuel. The advantage of the IGCC-SNG approach is that it reduces the emissions from coal plants without any significant usage of energy.*

Furthermore, if energy conservation is more strongly implemented, or we see good micro-CHP systems, the overall emissions from the coal fuelled generating sector will be reduced.

As regards hydrogen. The main concern will be the cost of conversion, which I would guess we be equal to or less than building heat distribution systems.

- you say CHP proponents put forward the cheery optimistic CHP percentages and things have and will move on further - I cannot speak for others but I tend to base my calculations on CCGT in CHP mode as 60% electrical efficiency and 20% heat usefully delivered or thereabouts (in any event 80% overall) - one of your paragraphs estimate overall CCGT efficiency of 90 to 95 %

I was trying to be honest about the potential for improvements in CCGT plant when I suggested that 90-95% of the energy could be turned into electricity plus heat. But please note in these very advanced plants, I also said that the electrical efficiency would be 55-60%. An electricity only CCGT would be running at just under 75%.

Given the very high heat domestic demand in the UK, which is likely to remain, there is not much point is increasing the efficiency of CCGTs to extremely high levels. The big advantage is that such units would be able to run during the summer when heat demand is very low. In winter ,an electrical efficiency of about 30% would be adequate.

- one FOE scenario would be for about 30+ GW of CCS fitted CHP (IGCC plus a few ASC coal power stations) about 12 GW of which would be industrial CHP. So there may be xx TWh/y of LOW-CARBON reject heat that could be utilised in heat grids - do suggest a figure for the electrical and thermal efficiency of IGCC feeding an urban heat network (say overall efficiency of 80%).

There is no surplus low grade heat from IGCC plants. This is one reason for calling them Integrated Gasification Combined Cycle. If one wants to obtain a lot of heat the steam turbine section of the plant would need to be shut down. This situation is worse than a conventional natural gas CCGT, because of the high ancillary power demand. Without doing any calculations I would guess, efficiency would fall from about 45% to less than 30%. Possibly down to the 20-25% range. CHP efficiency would be about 90%.

- Part of you paper is theoretical in the sense that its not taking sufficient understanding of what power stations in the UK will actually be on the ground in the 2020 - 2050 period - i.e. recent planning consents for the 8 GW of new CCGTs (unlikely to be your best shot turbines ?) and existing retrofitted or new schemes on existing sites - mostly badly located geographically to deliver heat to large heat grids but vacuum? insulated large diameter strategic hot water pipes may be able to deliver (e.g. Sizewell CHP) given the increasing value of low-carbon heat

Actually all of the paper is based on the assumption that the power stations will be built without any thought being given to CHP. What I have been saying all the way through the paper is that although CHP seems a brilliant idea, the energy savings are not that good, and implies huge modifications to the infrastructure.

There are three basic points which need to be answered by people who think that we need wide spread CHP in the UK. These are:

- *Where is the fuel coming from for* ***any form of fossil fuel power generation*** *in future?*
- *New housing will be built to reduce space heating demands to an absolute minimum*
- *Older houses, will get improved insulation. And energy demands will also drop because of higher energy prices. Is it sensible to put in heat mains for such dwellings .Should not the emphasis be on using gas and electricity more* economically?

- Costs of laying heat pipelines in urban housing areas : I think some in Claverton have tended to use £ 5k per dwelling (5 - 7 metres of frontage). One of your figures suggests much less than this. William has maintained that routing in the kerb area can reduce complications, impediments and hence costs and I have made the point that hollow 'kerbstones' may add even great cost reductions and convenience (plastic hollow kerbstones are commercially available and GRC may also be strong enough). The channel x-section created by simply removing existing concrete and stone kerbstones is possibly a third or more the way there (channel needs to be say two 8 inch pipes and could bundle other services too - fibre-optic broadband, new electric cables)

I wonder what a forty tonne lorry would do so such pipes? One of the biggest costs to British Gas and the Water Companies is the effect of trucks. And if such system were practical it would be easier to use them to route heavy duty electric cables

- you make the point that insulation will reduce heat need - but there is a trade off on costs between CHP and passive insulation - William makes the point that in existing urban areas it may be better to spend less insulation and let CHP do the work (e.g. aim for say 12 MWh/y rather than 9 MWh/y) - retrofitting existing urban areas with insulation may be physically difficult and resisted by public (disruption, visual amenity, less space etc)

Section 4 pointed out that even with slightly lower standards of insulation that you postulate 15MWh per annum rather than your 12MWh/a, the energy savings from CHP are quite modest and for a lot of the time space heating would not be needed.

- Dual use of district to (inner) city-wide heat grids - initial decades mainly for utilising reject low-carbon heat but progressively over decades more for energy STORAGE / delivery on demand - planning for several day winter anti-cyclone in scenarios of huge offshore wind (yours and mine and others in Claverton vision I think its fair to say) needs to be addressed - heat grids could include gasholder size hot water storage tanks at the edge of cites, industrial sites, etc (maybe close to where the offshore wind cables come ashore). I think I calculated a hot water storage of 3 TWh would keep urban stock warm in major winter windless period - that leaves the 30 + GW of IGCC / ASC and maybe 10 - 15 GW of mCHP, plus interconnectors + peaking plant + other to deliver the demand over those few windless days (you make the point that hot water storage is 10 times less volume than hydrogen. CHP pipeline investments would last 100+ years and kerb / hollow kerbstone routing could enable /facilitate low cost maintenance, extensions, replacement, and whatever changes in response to new technology, new heat sources/demands)

I have no trouble with the calculations, as this fits in with my arguments fro renewable heat. BUT where is the fuel coming from for CHP?

- Heat grids could store excess to grid demand electricity e.g. from offshore wind farms or baseload IGCC with CCS for that matter - I view energy storage as a major additional benefit of heat grids especially with highly variable renewables - i.e. the whole system scenario has to be considered and specified (so the reader understand the basic wider assumptions)

In Section 9 I have argued strongly that heat grids ought have a place

- You really need to look at interactions / benefits / disbenefits of heat pumps and heat grids and plugging in ground source geothermal sources

I think ground based heat pumps are not sensible. We should use stored water as a heat source for heat pumps.....I think the Danes are investigating this!

FROM IAN BYWATER

Hi Fred,

I enjoyed reading your paper today and submit the following for consideration.

Page 5. second para. This is termed the ADMD (after diversity maximum demand). When I planned housing estate cables in the 70's I used a figure of 3kW. Times change.

Page 7. Network losses are generally taken to be 5% but in fact, at peak times and due to the age of the network components, mainly the transformers, the losses can be as high as 20%!!

Comment, although mentioned later, the broad analysis does not separate space heating load from water heating load.

Page 10. Diesels operating in dual-fuel load are work a mention albeit still quire rare. WE have developed this for our AD farm biogas energy system.

Page 18. A plea to add bioenergy types when you list renewable energy! E.g. cows shit every day - it's very reliable!!

I agree with your conclusions as to how the UK should use the infrastructure it has in its gas reticulation network. Something we don't have now even in Christchurch as it was lost to telecoms cables when the gas works was closed decades ago.

Very best wishes,
Ian Bywater

Dear Ian,

Thanks for your comments. Here is my response;

Maximum Household Demand: I got this from a contact sometime ago. I thought 2 kW was a bit low, but even your 3kW per household will surprise most people.

Network Losses : The EU Directive has accompanying calculations which utilise network losses to work out the energy savings of CHP, compared to centralised power (Even when using these figures many CHP systems struggle to show that real energy savings are being made). Most of the losses are in the distribution and are given as about 5-6% (8% overall). I did do some calculations to determine losses at peak power, based on I^2R , but could not get them up to much more than 10%. Am I missing something? What about reactive power considerations?

What is being overlooked by the CHP enthusiasts is that if CHP becomes widespread, the local network will be used to distribute power and part of the energy savings disappear.

Water Heating Load: In well (or better) insulated houses, space heating will not be needed for most of the year. The only requirement will be for about 0.5-1.0kW for washing requirements. This is extremely peaky and gives another problem for CHP.

Biogas and Biofuel Engines: In the UK the population is so great that these can only make a small contribution to energy requirements....As I keep saying, what works in one country will not work somewhere else.

Closing Down the Gas Distribution Network in Christchurch NZ: Sweden made the same mistake, in closing down its gas works. In the UK, when old style coal gasification became uneconomic, British Gas made our gas from oil, using steam reforming (this is how I entered the Gas Industry. These processes kept the Industry going until North Sea Oil arrived).

I have pointed out that when gas runs out, it would be fairly easy to thread heavier electric cables though the gas pipes. These cables would carry power from renewable sources. The power level would need to be 3-4 times higher than that of today