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Large-scale combined heat and power

By Chris Burgess, director, Alpha Management Solutions Ltd

Combined heat and power (cogeneration) is the simultaneous generation of electricity and useable heat, in a single process in a building or at a site using a fossil fuel or a renewable energy source such as biomass. By generating electricity and heat at the point of use the requirement for centrally generated grid-electricity and on-site heat production is reduced, thereby offering the potential for reductions in operating cost and carbon emissions.

Combined heat and power (CHP) is a proven technology and given the right application can deliver positive financial and environmental benefits. In its simplest form CHP comprises a prime mover driving an electrical generator and a system to recover heat to be used for industrial processes, district heating schemes or space heating individual buildings. The heat recovered from the prime mover can also be used as the energy source for an absorption chiller in cases where cooling is required (tri-generation). For applications where the heat demand is limited to a proportion of the year, the addition of absorption cooling can extend the CHP run hours to improve the financial return.

The continued development of technology such as domestic scale micro- CHP, fuel cells and low emission engines and turbines means that in the future more energy users will be able to benefit from CHP technology. The use of biomass and biofuels as CHP input fuels is developing and tri-generation is often one of the low carbon technologies at the heart of the growing number of district energy schemes within the UK.

CHP plant is energy efficient because it converts around 80 per cent of the energy in the fuel to usable heat and power at the point of use. This compares with a combined efficiency of around 55 per cent when electricity is purchased from the grid and heating is provided by onsite fossil fuel heating boilers.

The UK's centralised electricity system has an average delivered efficiency of

around 40 per cent; in other words, less than half of the input primary energy is supplied as electricity at the meter. The remainder of the energy in the fuel is dissipated as unusable heat at the power station and from the distribution system. Even modern combined cycle gas turbine stations optimised for power generation only achieve a delivered efficiency of 45 to 50 per cent.

The efficiency of CHP delivers a financial advantage in that less primary fuel is consumed per unit of energy delivered. This financial benefit is reflected in a reduction in the site electricity bill, although the actual level of savings achieved depends upon the relative cost of the CHP, input fuel CHP, and the value of the electricity generated. CHP is a capital-intensive investment and to be viable the savings need to be sufficient to repay the installed cost within an acceptable period and cover the on-going costs of operation and maintenance.

Well-designed and operated CHP is more efficient than the current centralised power generation system and on-site boilers. Every unit of energy produced by natural gas fired CHP reduces the level of carbon dioxide emitted by around 35 per cent compared with the current mix of central generation.

The economic case for CHP is improved by exemption from the Climate Change Levy (CCL) provided the plant qualifies as "Good Quality" under the CHP Quality

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Assurance (CHPQA) Scheme. The key requirements are that the CHP must operate above certain heat and power efficiencies and not discharge significant heat to atmosphere. "Good Quality" CHP is eligible for Enhance Capital Allowances, which means most companies investing in CHP can write-off the whole cost during the first year of its operation.

Based on Government data at the end of 2013 Good Quality CHP capacity was just over 6GWe (7 per cent of the UK generation capacity) and generated 5.8 per cent of all electricity produced in the UK. Sixty-seven percent of the fuel used in these CHP schemes was natural gas with the use of renewable fuels at 10.5 per cent.

Of the 2,014 CHP installation 83 per cent are less than 1MWe in electrical output but represent just 5 per cent of total capacity, whereas schemes larger than 10MWe represent 80 per cent by capacity but only 3.4 per cent by number. Nearly 70 per cent of total electrical capacity is combined cycle gas turbine plant while reciprocating engines contribute 16 per cent followed by open cycle gas turbines at 7 per cent.

A recent report to government estimated the potential for CHP based purely on technical constraints was 29GWe in 2012 rising to 32GWe in 2020 and 34GWe in 2030, mainly as a result of anticipated growth in the service sector. The actual capacity estimated to be installed on cost effective grounds is somewhat less but represents a significant growth in the CHP market at 18GWe in 2020 rising to 20GWe in 2030.

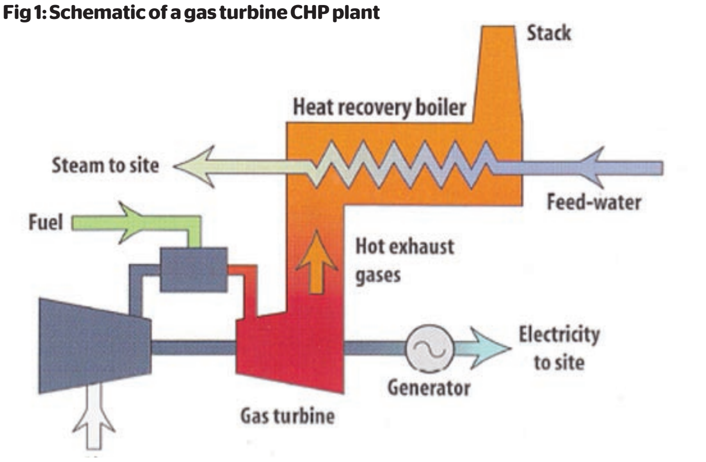
CHP is categorised by its electrical output and input fuel. CHP with an output above 1MWe is categorised as large scale CHP. Small scale CHP typically uses gas fired reciprocating engine packages whereas large scale CHP employs not only engine prime movers but also steam and gas turbines.

The reciprocating engines used in CHP are often spark ignition engines designed to operate on natural gas although biofuels, biogas and other recovered gases can be used. The efficiency of gas engines tends to be higher than that of gas turbines and there is a lower fall in efficiency when operated under part load.

Heat recovery from two sources

Heat produced by the engine can be recovered from at least two sources: engine and lubricating oil cooling providing hot water is at around 80OC, plus heat from the engine exhaust at around 400OC. The heat to power ratio ranges from about 1:1 to 2:1, with the engine cooling and exhaust heat in roughly equal proportions. The engine and lubricating oil must be cooled irrespective of whether or not it is required by the site and has

Fig 1: Schematic of a gas turbine CHP plant



implications for sizing and modulation control for this type of CHP.

The electrical efficiency ranges from around 30 per cent for smaller engines to 40 per cent based on Gross Calorific Value (GCV). Compression-ignition engines can be used for larger CHP up to about 15MWe and achieve higher efficiencies between 35 per cent and 45 per cent (GCV).

Gas turbines use high pressure combustion gases to deliver power to the turbine shaft. A proportion of the shaft power is required to drive the compressor that provides the high pressure air for combustion while the remainder drives the electrical generator. In a CHP configuration the exhaust gases are discharged from the turbine and provide the high-grade source of heat for the site.

Sometimes the exhaust gases can be used directly for heating but more commonly are passed to a waste heat boiler to produce steam or hot water. A gas turbine requires more air throughout than that required for just combustion, which means that the hot exhaust gases can be used for supplementary firing to efficiently increase the heat output. The ratio of useable heat to power for gas turbine CHP ranges from 1.5:1 to 3:1 without supplementary firing depending upon the characteristics of the individual gas turbine.

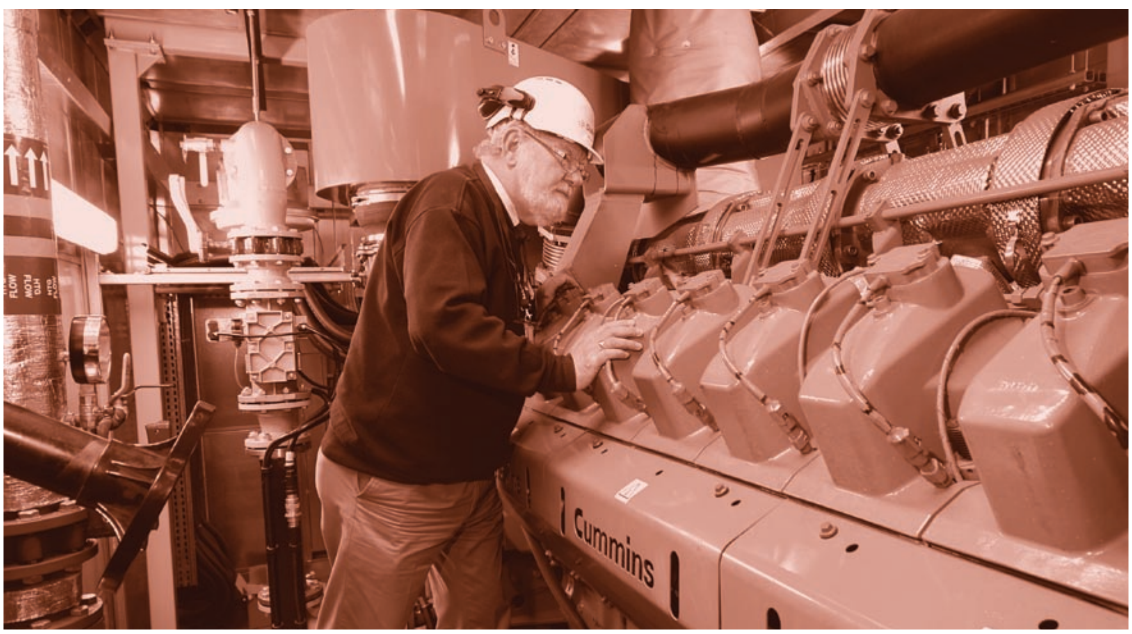
Gas turbines for CHP are available from about 1 or 2MW to over 200MW but start to become cost effective compared with engines at about 5MW. Electrical efficiency tends to be lower than similarly sized gas engines - typically between 25 per cent (GCV) for small turbines and 36 per cent (GCV) for large turbines. However, gas turbines are usually smaller and require less running maintenance than reciprocating engines.

Thermal output as high-grade heat

Another benefit of gas turbine CHP is that it delivers all the thermal output as high grade heat, which means they tend to be favoured for larger installations where a steam demand is present. However, gas turbines need to operate under steady conditions at or near to their full rated output because efficiency deteriorates at part load. In addition the power output reduces as the temperature of the inlet air increases.

The air and fuel supplied to the turbine must be free from particulates and contaminants that would cause corrosion. A high standard of air filtration is essential and premium fuels are most often used, natural gas being the most common. Gas turbines require a high pressure fuel supply or on-site gas boosters when gas-fired and this can represent a significant parasitic electrical load.

The power produced by a steam turbine depends upon the steam pressure available and how far the pressure can be reduced through the turbine before it is extracted for the site energy needs. The simplest arrangement is known as a back-pressure turbine, where all the steam flows through the turbine and is exhausted from the final stage at the pressure



corresponding to the temperature required by the site heating load.

If more than one grade of heat is required at the site the higher grade is supplied by extracting "pass-out" steam at the appropriate pressure part way through the turbine. The remaining steam continues through the turbine to generate additional power and finally exits at the conditions required for the remaining heating load. The amount of pass-out steam extracted can be controlled by the heat demand, so when the thermal demand falls, less steam is extracted and the electricity output increases – this makes this type of CHP very flexible.

However, steam-turbine CHP has more limited applications than gas turbines or engine-based systems because of the lower efficiency and the consequent high heat to power ratios. Traditionally steam turbines have been used when a very cheap low-premium fuel or by-product process heat was available but are now finding increasing application in combination with biomass steam boilers for renewable energy CHP.

Gas turbine exhaust gases provide a high-grade heat source that can be used for steam generation as noted above. On sites where there is a requirement for low-grade heat only or where additional electricity has a high value, the steam generated from the gas turbine exhaust can be passed to a steam turbine to generate additional electricity. Combined cycle CHP plant can convert 40 per cent or more of the fuel input into electricity.

Limited operating experience

The Organic Rankine Cycle is a relatively new technology with limited operating experience in the UK CHP market. The technology operates on the same principle as a steam turbine except that the working fluid is not water, but either a fluid with a relatively low boiling point, such as a refrigerant, or with a relatively high boiling point such as oil.

Low temperature fluids allow power to be generated at lower temperatures than conventional steam turbines and can achieve higher electrical efficiencies for smaller capacities. However, the working fluid is at such a low temperature after power generation it has limited heating value. The use of high temperature oils offers the opportunity to extract heat at a useful temperature for CHP heating applications.

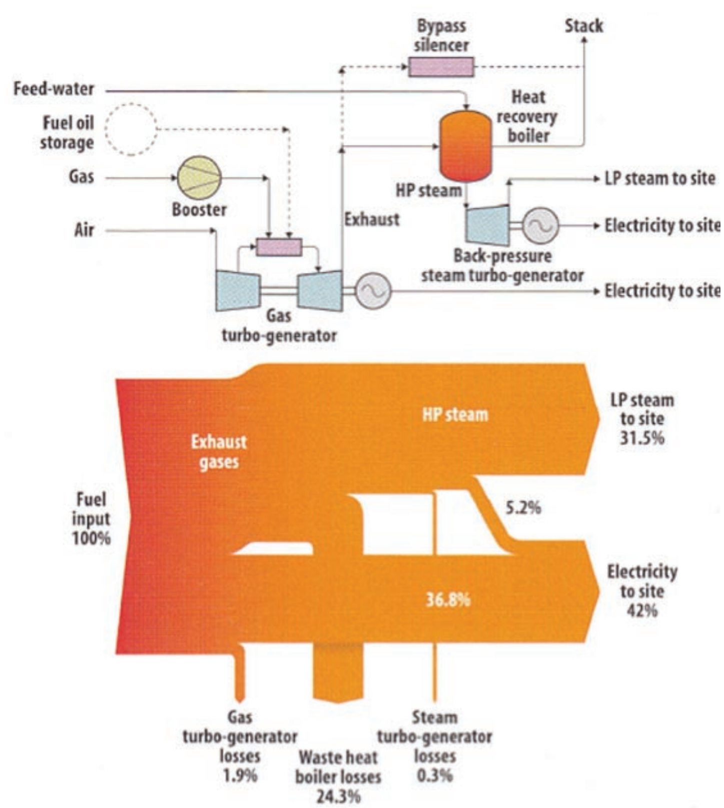
CHP plant is normally connected in parallel with the electricity distribution network and not designed to meet the site's full power demand. As the site demand varies any power requirement in excess of that provided by the CHP will be automatically drawn from the grid.

When the CHP generation output exceeds the site demand surplus power can be exported to the grid.

This type of connection is most common because the ability to have top-up and back-up power is regarded as an essential facility to ensure security of power supply but there are important safety requirements for the CHP plant and the site electrical system.

The CHP alternator must be equipped with synchronising equipment so that the phasing of the power is matched with the local supply before it is connected. The generator and the switchgear must be equipped with protection equipment, so that the generator is automatically and instantaneously disconnected in the event of any system instability. These and other connection requirements are covered in the Energy Networks Association G59 Engineering Recommendations.

Fig 2: Simple schematic of combined cycle CHP and its energy balance



CHP should normally be sized based on the heat and power base loads of the site because it will operate at greatest efficiency, thereby maximising savings, when running as close as possible to full output, provided all of the output is used.

This means CHP is often, but not always, sized and modulated based on the site's heat demand with additional power imported from the grid. With gas turbines and engine prime movers the amount of waste heat available is approximately proportional to the fuel input so the plant can to a degree be modulated to avoid wasting heat at times of very low heat demand but efficiency will fall particularly with gas turbines. If the value of power is very high compared to the cost of fuel in some cases it may be economic to generate maximum power and waste excess heat for short periods.

Large-scale CHP represents a significant long-term capital investment and the project financial appraisal will probably be based on discounted cash flow and internal rate of return methods and must assess the full ownership and maintenance costs on a life cycle basis.

There is a wide variety of investment models for financing combined heat and power including "on balance sheet" options such as internal financing or leasing but more often "off balance sheet" options such as equipment supplier finance or an ESCO (Energy Services Company) contract are now used.

The exact terms of ESCO contracts vary but often the ESCO will design, install, finance, operate and maintain the CHP plant on the company's site. In other cases the ESCO will be given responsibility only for the operation and maintenance of the plant. In both cases the ESCO contractor supplies heat and power to the site at agreed rates and may take additional responsibility for fuel purchase.

Web sites:

1. CHP Quality Assurance Scheme (CHPQA) https://www.gov.uk/combined-heat-power-quality-assurance-programme
2. The Association for Decentralise Energy http://www.theade.co.uk/
3. A guide for Combined Heat and Power (CHP) developers on different CHP technologies. https://www.gov.uk/government/publications/combined-heat-and-power-chp-technology

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Please mark your answers on the sheet below by placing a cross in the box next to the correct answer. Only mark one box for each question. You may find it helpful to mark the answers in pencil first before filling in the final answers in ink. Once you have completed the answer sheet in ink, return it to the address below. Photocopies are acceptable.

QUESTIONS

1. A CHP unit generates?
- ☐ air conditioning
- ☐ heat
- ☐ electricity
- ☐ heat and power simultaneously

2. CHP plant converts how much of the input fuel to usable heat and power?
- ☐ 20% ☐ 40%
- ☐ 80% ☐ 100%

3. What is the average efficiency of the UK's central electricity generation system?
- ☐ 40% ☐ 50%
- ☐ 60% ☐ 70%

4. What proportion of all electricity generated in the UK is from "Good Quality CHP"
- ☐ 1.8% ☐ 3.8%
- ☐ 5.8% ☐ 9.8%

5. Which of the following ranges of electricity efficiencies (ratio of electricity output to fuel input) would you expect for gas turbine CHP?
- ☐ 10 to 16% ☐ 25 to 36%
- ☐ 60 to 75% ☐ 80 to 98%

6. Which of the following is the key advantage of gas turbine CHP?
- ☐ Higher efficiency than engine based CHP
- ☐ It needs a high pressure fuel supply
- ☐ Turbine efficiency increases under part load
- ☐ Supplies high-grade heat

7. Which of the following three statements is not true?
- ☐ CHP is a carbon efficient technology for the production of on-site heat and power.
- ☐ CHP units have a capital cost about the same as standard boiler technology.
- ☐ Maintenance costs of the CHP unit are important in the economic feasibility of any CHP scheme
- ☐ CHP can reduce site energy costs

8. What is the typical CO2 reduction for gas fired CHP compared with current centralised generation?
- ☐ 25% ☐ 35%
- ☐ 50% ☐ 60%

9. Which of these is likely to improve the financial benefit of CHP?
- ☐ Rising electricity prices
- ☐ Falling electricity prices
- ☐ Rising gas prices
- ☐ None of these

10. Why is most CHP connected in parallel with the electricity grid?
- ☐ It is the only option
- ☐ It is safer to do so
- ☐ It allows the site to import top-up power
- ☐ It improves CHP efficiency

Please complete your details below in block capitals

Name .... (Mr. Mrs, Ms) ....

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