Factfiles

The Institution of Engineering and Technology

Combined **Heat and Power** (CHP)

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The Institution of Engineering and Technology

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Introduction

The conversion of primary fossil fuels, such as coal and gas, to electricity is a relatively inefficient process. Even the most modern Combined Cycle plants can only achieve efficiencies of between 50-60%. Most of the energy that is wasted in this conversion process is released to the environment as waste heat - power station cooling towers are a very recognisable sight. Each year, UK power stations typically reject more energy as waste heat than is consumed by the entire domestic sector[1].

The principle of Combined Heat and Power (CHP), also known as co-generation, is to recover and make beneficial use of this heat, significantly raising the overall efficiency of the conversion process. The very best CHP schemes can achieve fuel conversion efficiencies of the order of 90%. Most of the heat wasted in electricity generation is carbon-based and so if CHP could be more widely deployed there are potentially significant energy, environmental and economic benefits which could be realised.

CHP has always played an important role in the UK's energy supply. In the early years of the UK electricity supply industry most power stations were physically close to the demands they supplied. This made it easier for them to supply customers with heat as well as electricity. The trend towards large power stations that gathered pace in the 1960s meant that electricity was no longer generated at locations that had an adjacent heat load and until the 1990's UK CHP capacity declined. However, the privatisation of the electricity industry in 1990 encouraged fresh thinking regarding generating technologies. The commercial benefits that could be gained from the inherent fuel efficiency of CHP led to new investment in CHP capacity, primarily in the industrial sector. The opportunity to reduce emissions of carbon dioxide and other pollutants was also well recognised and the government set a target to increase CHP capacity to 10 GW by 2010. Specific incentive mechanisms were put in place to help achieve this as part of the government's CHP Strategy[2].

In the decade to 2000, capacity increased strongly to 4.5 GW, representing an average growth rate over the period of some 8% per annum. However, difficult market conditions have slowed this growth rate from 2001. Nevertheless, the overall capacity has still been increasing slowly. It peaked in 2005 at 5.6 GW and BERR data for 2006 shows capacity at 5.5 GW[3].

In 2006 CHP plants produced some 28 TWh of electricity and 54 TWh of heat; hence CHP currently produces approximately 6% of the UK's electricity supplies.

From Principle to Reality

The CHP principle can be realised in many ways, using a range of fuels and prime movers and implemented in capacitates from 1 kWe to 100s of MWe. CHP schemes operate for decades and so current UK CHP capacity comprises schemes based on old and new forms of CHP technology.

The main technologies used in current UK CHP schemes are:

- Gas Engines - reciprocating engines, similar to those used in road vehicles, using natural gas as fuel, driving a generator and recovering heat from the engine exhaust and cooling jacket. Sizes range from 10 kWe to several MWe. This form of CHP is widely used in buildings where the use of low grade heat in space and water heating systems enables a high level of waste heat recovery.
- Gas Turbines - derived from aerospace and industrial designs, these produce exhaust gas at high temperature, which is ideal for generating steam or direct use in drying processes. Sizes range from below 100 kWe (e.g. micro-turbines) to over 100 MWe. This form of CHP is commonly found in industry, e.g. the process industries such as the chemicals or paper industries, which have high demands for steam.
- Steam Turbines - this technology was the mainstay of industrial CHP capacity before the introduction of gas turbines and is based on the designs found in coal fired power stations. Sizes range from around 100 kWe to many MWe. As the heat output is in the form of steam the main applications are also in the process industries.
- Combined Cycle Gas Turbines - these combine a Gas Turbine feeding a Heat Recovery Steam Generator (HRSG) which in turn drives a Steam Turbine. Sizes range from 20 MWe to many 100's of MWe. This system offers a high power efficiency and is also normally found in the process industries.
- Absorption Chilling - this technology uses heat (as hot water or steam) to produce chilled water or chilled glycol. In combination with one of the other CHP technologies this can be used to provide power, heat and chilling. Such "tri-generation" systems are found in buildings and on some industrial sites

Whilst the most common fuel since 1990 has been natural gas, the range of fuels that can be used by these technologies is also wide and includes:

- natural gas
- landfill and sewage gas
- fuel and gas oils
- coal, lignite and coke
- biomass and biogas
- solid waste, e.g. refuse, tyres
- waste gases, e.g. refinery off gas
- waste process heat

The following figures provide typical schematics for a small scale CHP plant used in a building and a larger gas turbine CHP plant used in industry.

Economic and Environmental Performance

CHP is traditionally sized by reference to base load heat demand. This design approach will result in the highest level of heat utilisation and potentially therefore the greatest environmental and economic benefits. In many cases this approach would lead to generation of electricity in excess of site requirements. Exported electricity from a CHP plant has a lower value than the electricity generated and used on site. This is due to a number of factors including the buy/sell spread, the network costs to deliver the electricity to a customer, and market participation costs. These factors and the risks involved in electricity trading can result in a compromise having to be made between sizing to maximise economic or environmental benefits.

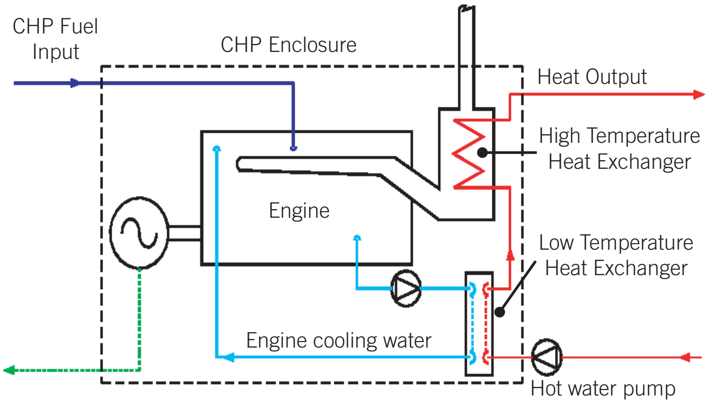

Figure 1 Packaged Gas Engine CHP with single grade hot water heat output and no heat dump.

The mis-match between economic and environmental efficiency flows from a number of energy pricing issues. One is that the environmental costs of electricity and heat production - known as the cost externalities - are not yet fully incorporated in electricity prices. Another is that the added value of electricity generation close to consumers - known as embedded generation benefits - may only be partly recoverable by the CHP owner.

In both economic and environmental terms the electricity output from CHP is more valuable than the heat output. Hence the Power Efficiency (ηPower) is more important than the Heat Efficiency (ηHeat) in determining economic viability.

As the value of electricity is greater than the value of heat, many CHP schemes have the ability to reject heat, allowing the scheme to generate electricity at times of highest electricity prices, or allowing the scheme to run to supply essential loads during a power outage. However if the design or operation of a CHP scheme was to entail significant waste of the heat available, then the environmental benefits are also significantly reduced.

A number of financial incentives are on offer to recognise the environmental and energy benefits of "Good Quality" CHP[4]. These incentives include Climate Change Levy exemption for qualifying fuel input and power outputs. To ensure that the incentives are in line with the benefits offered, the UK has developed the CHP Quality Assurance programme to assess, monitor and certify CHP performance[5].

The use of an audited certification scheme linked to the availability of financial incentives partly offsets the mis-match between the economic and environmental efficiency of CHP within current markets and the Government continues to keep the situation under review.

Two major factors affecting the economics of CHP are the relative cost of fuel (principally natural gas) and the value that can be realised for electricity. In the 1990s, electricity prices declined in real terms. For most of that time gas prices also fell, but rose significantly in 2000 and 2001, due to structural changes in the gas market. The variability in the relationship between gas and electricity prices is often cited as an uncertainty that constrains investment in CHP.

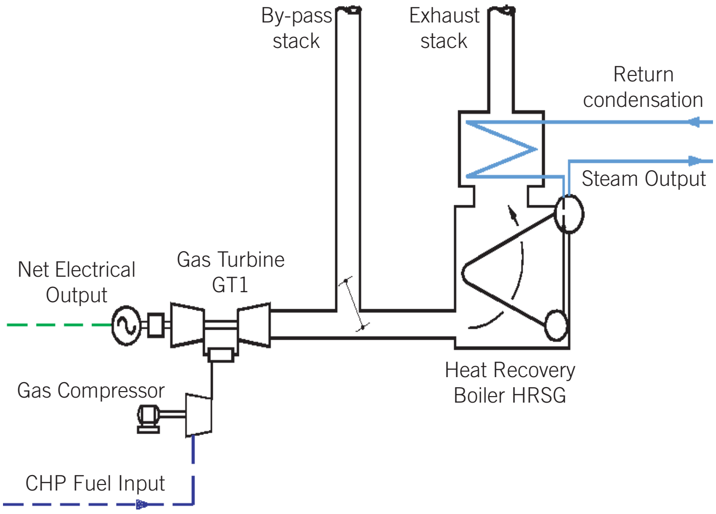

Figure 2 Gas turbine with Heat Recovery Steam Generator (HRSG)

The Future for CHP

As with larger scale power generation technologies, efficiency and environmental performance continue to improve. Looking ahead there are several likely developments to note:

- Fuel Cell CHP: offers the opportunity for higher levels of Power Efficiency in the range 50-60%;
- Micro-CHP: a range of technologies including Stirling Engines and Fuel Cells are being developed to provide a CHP package for individual homes;
- Renewable Energy: a number of technologies are being developed which will assist the use of renewable fuels for CHP. These include the use of gasifiers to convert biomass fuels for use in gas engines, gas turbines or fuel cells.

These developments mean that it is likely that CHP systems will retain or enhance their advantages of high efficiency and low environmental impact. Hence as the environmental sustainability of energy supplies in the UK and world-wide becomes increasingly important, growth in the use of CHP is expected to continue. The UK government has published its strategy for CHP and this is available on the Defra website[6]. The opportunities for the further development of CHP were also considered in the government's Energy Review of 2006[7] and Energy White Paper of 2007.

Further Information

- CHPA - The UK CHP Trade Association:
  http://www.chpa.co.uk
- The CHP Quality Assurance programme (CHPQA):
  http://chpqa.decc.gov.uk/
- DECC UK Energy Statistics:
  http://www.decc.gov.uk/en/content/cms/statistics/energy_stats/energy_stats.aspx

End Notes

1. Data from the DECC CHP statistics:
   http://www.decc.gov.uk/en/content/cms/statistics/energy_stats/source/chp/chp.aspx
2. DECC
   http://www.decc.gov.uk/en/content/cms/meeting_energy/chp/chp.aspx
3. DTI DUKES 2006
4. Good Quality CHP refers to CHP generation that is energy efficient in operation:
   http://chpqa.decc.gov.uk/
5. CHPQA
   http://chpqa.decc.gov.uk/
6. DEFRA
   http://www.defra.gov.uk/Environment/climatechange/uk/energy/chp/pdf/chp-strategy.pdf
7. BERR
   http://www.berr.gov.uk/energy/review/page31995.html

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