HEAT NETWORK PARTNERSHIP FOR SCOTLAND

District Heating Strategy Factsheets

Application of Combined Heat and Power in district heating

Contents

1 Introduction

Combined Heat & Power (CHP) is a highly fuel efficient technology which generates electricity and puts to good use heat which would otherwise be wasted. It is widely used in UK buildings and in the right circumstances is a very cost effective means of powering a heat network. Conventional gas CHP cannot be considered a renewable technology, however it is low carbon in comparison to conventional electricity generation due to it's efficiency. Primary fuel sources for CHP can include a wide range of fuels as well as biomass, waste, hydrogen & geothermal. This paper discusses various CHP technologies and their application to district heating before highlighting the key factors affecting suitability and guidelines for building a buisness case for CHP.

2 Learning Objectives and Outcomes

2.1 Learning Objectives

At the end of this module, you will:

- Understand the key principles of combined heat and power;
- Understand the key combined heat and power technologies, their applications and advantages and disadvantages;
- Know how to prioritise the opportunities for combined heat and power.

2.2 Learning Outcomes

On completion of this module, you will be able to:

- Describe the principles of CHP and the benefits that it can provide;
- Recall the regulatory incentives that the government has put in place to support CHP;
- Recognise the different types of CHP plant available and their applications, particularly in respect of those relevant to public sector organisations;
- Conduct an initial assessment of whether a site is suitable for CHP, including what type and size of plant will be might be;
- Identify the options available for financing CHP, which is a relatively high capital item; and
- Begin to build a business case for installing CHP.

3 Introduction to Combined Heat and Power

The process of generating electricity from burning fuels will always result in the production of heat that must be removed. Vast amounts of heat are wasted from conventional ways of generating electricity. In today's coal and gas fired power stations deliver overall efficiencies of between 35% and 55%, meaning that up to two thirds of the overall energy consumed is lost to the atmosphere via cooling towers.

By contrast CHP systems are designed so that much of the heat produced as a consequence of generating electricity can be put to good use for local space and water heating or for industrial processes. Put simply, Combined Heat and Power (CHP) integrates the production of usable heat and electricity, in one single, highly efficient process.

Their relative sophistication means that the overall efficiency of CHP plants can reach in excess of 80% at the point of use. This ability to deliver high efficiency means CHP can bring energy, carbon and financial savings.

3.1 What is CHP?

Figure 3.1 illustrates how Primary Energy Savings arise from CHP compared with the equivalent separate generation of heat and power.

In a certain time, a building requires 100 units of electricity and 160 units of heat. Conventionally, the 160 units of heat will be produced from an on-site boiler with an efficiency of say 80%, which means that the boiler will consume 200 units of fuel. At the same time the 100 units of electricity taken from the grid will require around 265 units of fuel to be burnt at the power station at an overall efficiency of around 38%. The total fuel required therefore is 465 units.

In the case of CHP the same requirements can be met by a CHP plant consuming 325 units of fuel, generating electricity at an efficiency of 32.5% and recovering 160 units of useful heat. The overall efficiency of conversion of fuel to useful heat and electricity is therefore 80% and the Primary Energy Saving is 140 units of fuel, or 30%, compared with the separate provision of heat and power. There are also associated reductions in emissions and costs.

In this example, the delivered energy is the energy in its final form as delivered to the building i.e. 160 units of heat and 100 units of electricity. The primary energy is the amount of raw fuel required to provide the delivered energy, which is always smaller than the primary energy because of conversion inefficiencies.

This example has deliberately been kept simple; there is a range of factors that need to be properly considered in appraising whether CHP is appropriate and viable for a specific application.

Figure 3.1 – Separate Generation of Heat and Power and Combined Generation of Heat and Power

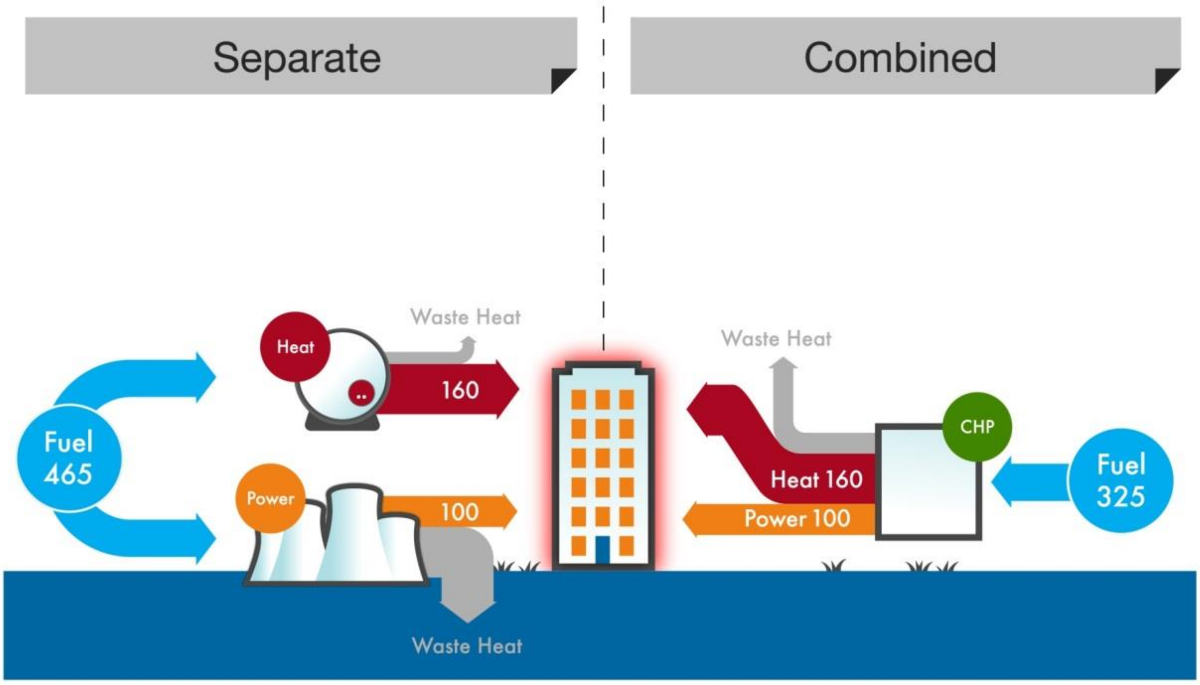

Image courtesy of http://chp.decc.gov.uk/cms

3.2 Policy Background

The Scottish Government, through the Renewable Heat Action Plan for Scotland[1], has set a target of 11% of heat consumed in Scotland be generated by renewable sources by 2020. CHP can play an important role in achieving that goal.

The Climate Change (Scotland) Act 2009[2] introduced ambitious targets and legislation to reduce Scotland's emissions by at least 80% by 2050. All public sector bodies in Scotland have duties under the Act to reduce carbon emissions in line with the emissions reduction targets. Heating accounts for a large element of the direct carbon emissions of many public sector bodies, so CHP can make a significant contribution to achievement of these targets.

Correctly managed, CHP can deliver a significant reduction in net carbon emissions when compared with fossil fuels. The amount of carbon reduced will depend on the efficiency of the CHP system.

There are financial rewards for saving carbon including:

- Reduction of the Climate Change Levy (CCL) which is charged on purchases of gas, LPG and electricity by public bodies[3];

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[1] Please refer to http://www.gov.scot/Topics/Business-Industry/Energy/Energy-sources/19185/Heat/RHUpdate11 for more information [accessed 03/05/2017]

[2] Please refer to www.scotland.gov.uk/Topics/Environment/climatechange/scotlands-action/climatechangeact for more information [accessed 03/05/2017]

[3] Please refer to www.gov.uk/green-taxes-and-reliefs/climate-change-levy for more information [accessed 03/05/2017

- Reduction of payments under the Carbon Reduction Commitment Energy Efficiency scheme (CRC)[4]. The CRC scheme is a mandatory carbon emissions reporting and pricing scheme to cover all organisations in the UK using more than 6,000MWh per year of qualifying electricity supplied through settled half hourly meters. The scheme is managed, on behalf of the UK Government's Department of Energy & Climate Change (DECC) by the Scottish Environment Protection Agency; and
- Reduction in the quantity and cost of emission allowances purchase by very large energy users who are part of the EU Emissions Trading Scheme (EU-ETS)[5].

3.3 CHP Quality Assurance Programme

The CHP Quality Assurance programme (CHPQA)[6] is a government initiative providing a practical, determinate method for assessing all types and sizes of Combined Heat & Power (CHP) schemes throughout the UK.

The CHPQA aims to monitor, assess and improve the quality of UK Combined Heat and Power. CHPQA, by assessing CHP schemes based on their energy efficiency and environmental performance, ensures that the associated fiscal benefits are in line with environmental performance.

Successful CHPQA certification grants eligibility to a range of benefits, including Renewable Obligation Certificates, Renewable Heat Incentive, Carbon Price Floor (heat) relief and the Climate Change Levy exemption (in respect of electricity directly supplied).

The CHPQA judges the energy efficiency of CHP on its electrical efficiency and on a Quality Index (QI). The QI is a measure of the overall energy efficiency of CHP and the level of primary energy saving that it can deliver compared to the alternative forms of separate heat and power generation. The QI Index is explained in the CHPQA Standard published by the Department of Energy and Climate Change.

The CHP is considered Good Quality if the electrical efficiency is above 20% and the QI exceeds 100 for existing schemes, and if the QI exceeds 105 for upgraded or new schemes.

Certification under CHPQA provides a route to a number of benefits[7].

GQCHP are exempt from the CCL on the fuel they utilise (assuming they meet a power efficiency threshold of 20% otherwise this exemption is scaled back) and on the qualifying power output generated. Schemes are fully exempt from CCL on their fuel inputs and power outputs where scheme meet or exceed the power efficiency and QI thresholds. However this exemption is ‘scaled back’ where these thresholds are not met so that only a proportion of fuel or power is exempt[8].

The Government introduced a floor price for carbon to stabilise price signals to investors in low carbon technologies. This has been implemented through the CCL system, introducing new rates levied upon supplies of taxable commodities to power generators (including CHP);

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[4] Please refer to www.scotland.gov.uk/Topics/Environment/climatechange/international-action/uk/CRC-1 for more information [accessed 03/05/2017]

[5] Please refer to www.scotland.gov.uk/Topics/Environment/climatechange/international-action/eu/EUETS for more information [accessed 03/05/2017]

[6] Please refer to http://chpqa.decc.gov.uk for more information [accessed 03/05/2017]

[7] Please refer to www.gov.uk/combined-heat-and-power-incentives for more information [accessed 03/05/2017]

[8] Please refer to www.gov.uk/green-taxes-and-reliefs/climate-change-levy for more information [accessed 03/05/2017]

these rates are known as CCL carbon price support (CPS) rates[9]. GQCHP certified with CHPQA are subject to the following benefits:

- Complete exemption for GQCHP with installed capacity of 2MWe and below; and
- Exempting GQCHP (>2MWe) from CPS on fuel for heat and, from April 2015, electricity consumed on site.

GQCHP schemes are able to claim a refund of Hydrocarbon Oils duty on oil used to generate electricity in respect of an annual operation (assuming they meet a power efficiency threshold of 20%)

Renewable Heat Incentive provides support for a biomass and bio liquid-fuelled GQCHP. Tariffs for biomass fuelled GQCHP currently stand at 4.1p/kWh, compared to 1p/kWh for large scale biomass boilers.

[9] Please refer to www.hmrc.gov.uk/climate-change-levy/carbon-pf.htm for more information [accessed 03/05/2017]

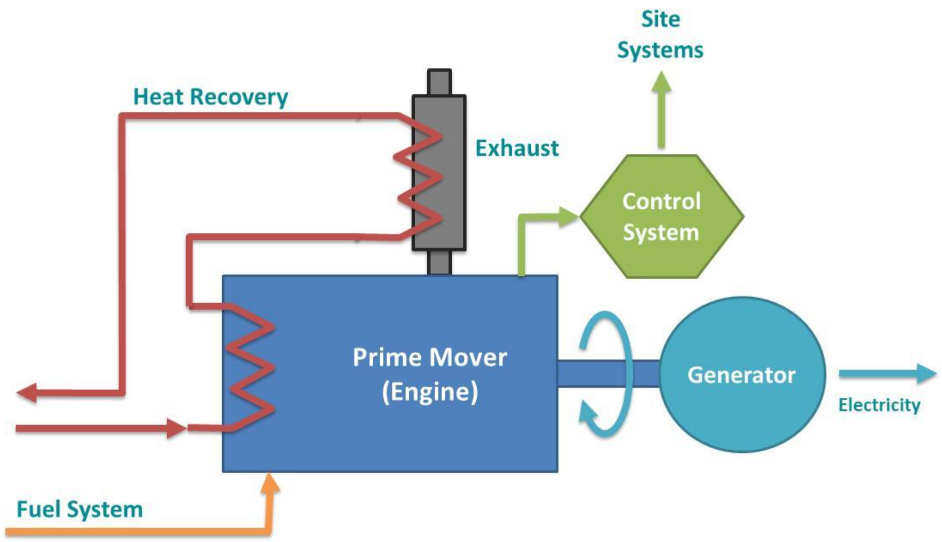
4 Technology Overview

4.1 How CHP Works

A CHP system generally comprises:

- Some form of heat engine (the prime mover), which produces mechanical power that drives an electrical generator. Occasionally the mechanical power is used directly to drive a mechanical load, such as a pump;
- Heat recovery systems;
- A fuel system;
- An exhaust or flue system;
- Control systems and integration with site systems such as BEMS; and
- Interfaces with site electricity and heat distribution systems.

Figure 4.1 - CHP System



4.2 Fuel

A wide range of fuels can be used in powering CHP schemes. Natural gas is the most commonly used fuel for CHP, but where there is no available gas supply, fuel oils are the alternative. An increasing number of CHP schemes firing on liquid and solid biomass and wastes are being implemented. Biogas, typically sourced from anaerobic digestion plant, is also a rapidly expanding fuel source.

The choice of fuel will be down to a range of site specific factors and project goals, such as:

- Fuel availability and cost;
- Fuel carbon content;
- Plant size and type;
- Fuel delivery and storage facilities required; and
- Plant maintenance requirements and cost.

Available fuel options will also influence the possible types of CHP plant and the financial viability of the project.

4.3 CHP Technology Types

CHP technologies can be categorised into those that are established and those that are emerging.

The different technologies are generally referred to by reference to the type of prime mover and the fuel. They are each suited to different fuels, energy demands, grade or temperature of heat required and other site specific requirements. There are also a number of emerging fuels processing technologies.

Internal Combustion Engine CHP

Internal combustion engine CHP systems are the most commonly used technology found in public sector applications. The engines used in CHP systems are reciprocating engines that operate on the same principles as their petrol and diesel automotive counterparts and are available in capacities ranging between 20kW to 16MW electrical output.

The normal convention of quoting CHP size is in terms of rated electrical output: MegaWatts 'e'.

There are two types of internal combustion engine used in CHP systems:

- Spark-ignition gas engines are available at outputs of up to around 4MWe, and operate on gaseous fuel only; and
- Compression-ignition (or diesel) engines are available at power outputs of up to around 16MWe and can be designed to operate on gas-oil, heavy fuel oil or a mixture of gas (up to 95%) and oil (5%).

Internal combustion engine efficiency is inherently better than that of gas turbines, and there is very little drop in engine efficiency when operated at part load – equipment suppliers can typically provide units that will modulate down to 50% of the rated electrical output. They can operate at very high availability levels. The heat to power ratio of this type of plant, which is simply the ratio of useful heat generated to electricity generated, ranges from about 1:1 to 2:1 depending on engine mechanical efficiency and the extent of the recovery of usable heat.

Engines and their lubricating oil must be cooled and so there is a supply of heat in the form of hot water at up to 120°C that will produced irrespective of whether or not it can be used. In addition, exhaust heat is available at temperatures of up to about 400°C. Cooling and exhaust heat comprise roughly equal proportions of the total heat produced by the engine. Commonly, heat is recovered from both sources to supply a site's low temperature wet heating system.

Internal Combustion engine based CHP systems are frequently delivered as a package ready for installation and connection to the fuel supply, Building Energy Management System (BEMS), and electricity and heat distribution systems. Such packages are of a compact design and can be mounted in existing boiler rooms or within integrated environmental enclosures, replacing or supplementing existing boiler capacity.

Although natural gas is the most commonly used fuel, biogas from anaerobic digestion of waste organic material is increasingly being used in such systems.

Gas Turbine CHP

CHP schemes based on gas turbines are mainly used in industrial applications, though they are sometimes suitable for particular applications in the public sector such as larger hospitals, universities and district heating schemes.

Gas turbines use pressurised combustion gases from fuel burned in one or more combustion chambers to turn a series of bladed turbine wheels and rotate the shaft on which the blades are mounted. This shaft delivers the power output from the turbine, some of which is required to drive the compressor that provides the high pressure air intake for the turbine. The remainder of the power drives the external load, usually an electrical generator. The air compressor and generator may be driven from a common shaft (single-shaft machine) or they may be independently driven (dual or multi-shaft machine). Gas turbine based CHP schemes are usually less than 15MWe output, with most in the range 3-12Me.

Power efficiencies are typically in the range of 25-35% so are generally lower than comparable internal combustion engine systems.

Gas turbines produce exhaust gases typically in the range 400-550°C. Although these gases can be used directly for process use such as drying, they are usually passed to a heat recovery boiler for the generation of steam or hot water. Depending on the particular turbine and the recovery of heat, overall efficiencies of around 80% are achievable and Primary Energy Savings of up to 20%.

The most common fuel used is natural gas, but the turbines can also be fired on other gaseous or distillate fuels. Some installations use natural gas on a cheaper interruptible tariff, with gas-oil as the standby fuel. Power output can be increased by steam injection into the turbine, which also helps to reduce emissions of nitrous oxides.

Where the site’s heat requirement exceeds the heat available in the exhaust gases, or is variable, a burner can be incorporated in the ducting between the turbine and the heat recovery boiler to increase the temperature of the exhaust gases and improve the heat output of the plant; this is known as supplementary firing and can increase the overall Primary Energy Saving. Supplementary firing can also be applied with larger internal combustion engine systems.

The ratio of usable heat to power ranges from 1.5:1 to 3:1 in a system without supplementary firing, depending on the characteristics of the individual gas turbine.

Steam turbines can be used together with a gas turbine to increase the total output of electricity, converting 40% or more of the original fuel energy into electricity and, if supplementary firing is also employed, provide the most flexible CHP systems currently available. In these ‘combined cycle’ or CCGT systems, high-grade exhaust heat from the gas turbine is fed to a heat recovery boiler, and the steam produced is passed to a steam turbine to generate additional electricity. The lower pressure steam from the steam turbine is then available for site use.

Steam Turbine CHP

Steam turbines are also employed for CHP systems in their own right. Their attraction is that they can use any fuel – solid, liquid or gaseous. The fuel is burned in a boiler to produce high-pressure steam that is then passed through the turbine, generating electricity. Steam turbine CHP is very reliable, and turbines can achieve a long-term availability of up to 99%. Units are available with power outputs of 0.5MW upwards. The ratio of usable heat to power in a steam turbine CHP set is unlikely to be less than 3:1 and may be 10:1 or more. There is no ‘typical’ steam turbine CHP set, as each is very specific to its site conditions.

Steam-turbine CHP has more limited applications than gas turbine and engine-based systems. For new applications, steam turbines are usually the technology of choice when a very cheap, low-premium fuel (e.g. waste material) not suitable for internal combustion engines is available. In the public sector, the most likely applications for steam turbine based CHP installations will be in conjunction with biomass boilers.

Steam turbine CHP can be categorised according to at what stage heat, in the form of steam, is extracted from the turbine. The simplest arrangement is the back-pressure turbine, where all the steam flows through the machine and is exhausted from the turbine at the pressure required by the site. Where steam is required at more than one pressure, higher pressure steam can be supplied by extracting ‘pass-out’ steam at an intermediate point in the turbine. The rest of the steam continues to the exhaust, thereby generating further power, and exits to the process at the lower pressure. Steam pass-out can also be used in conjunction with a condensing arrangement to maximise power output, this is achieved by expanding the steam down to a vacuum using a condenser and ejectors to maintain the vacuum. This produces heat at such a low grade that it is not generally useful thereafter.

Steam turbine CHP only produces significant amounts of power when the steam input is at high pressure/temperature and the heat output is relatively low-grade. In order to maximise the power generation, higher steam pressures are frequently selected, increasing both the capital costs of the steam boiler and plant running costs. The optimum choice is a compromise between output and costs that reflects plant size and the pass-out/back pressures required.

Emerging Technologies

In addition to the more established types of prime mover, Stirling Engine, fuel cell and Organic Rankine Cycle (ORC)-based CHP are emerging in the UK market but are still essentially under development.

A Stirling engine is like a steam engine in that all its heat flows in and out through the engine wall. Unlike the steam engine's use of water in both its liquid and gaseous phases as the working fluid, the Stirling engine encloses a fixed quality of permanently gaseous fluid such as air or helium. As in all heat engines, the cycle consists of compressing cool gas, heating the gas, expanding the hot gas, and finally cooling the gas before repeating the cycle. Theoretically Stirling engines should provide high power efficiencies. They also have the benefit of fuel flexibility as the fuel combustion is external to the working fluid driving the cycle.

A fuel cell converts the chemical energy in a fuel directly into electricity though an electro-chemical reaction. In the conversion process heat is released which can be recovered for useful purposes. Typical fuel cell technologies for CHP utilise natural gas (or biogas). These systems currently are more expensive than Stirling engines but can delivery higher electrical efficiencies of around 55%.

The aim in developing micro-turbines is to increase the range of gas turbine plant available to a size range around 25-250kWe. Power efficiencies are anticipated to be in the range 15-25% (non-recuperated) to 25-30%. Similarly smaller internal combustion engines and steam turbines are being developed.

Organic Rankine Cycle (ORC) systems can be used to utilise waste or low-grade heat to generate electricity. In their usual configuration, ORC system are not strictly a CHP technology as their only output is electrical power but they can often be incorporated into a CHP system to enhance the overall power efficiency and utilise greater amounts of waste heat. Some biomass CHP systems utilise ORC technology as an alternative to a high pressure steam turbine.

In addition Anaerobic Digestion and Advanced Thermal Treatment are emerging technologies with respect to the production of fuel for CHP systems.

Anaerobic Digestion is used to process organic wastes. The process produces a biogas which can then be fired in internal combustion engines. The process is well established and its use in CHP applications is increasing steadily.

Advanced Thermal Treatment (ATT) covers a handful of similar and sometimes coordinated technologies which are used to process biomass or solid wastes. Pyrolysis occurs under starved oxygen conditions and gasification under reduced oxygen conditions. There are a number of subtle variations of the technologies in development, but all produce a synthetic gas (syngas) of varying quality and calorific value (depending on input feedstock). The syngas can be fired in either reciprocating engines or steam raising boilers, depending on its quality and on the site specific requirements. It should be noted that ATT technologies remain at the early stages of development, with very few schemes currently in commercial operation.

Applications

Almost every conceivable area of energy consumption can be served by some form of CHP. This includes industrial sectors, buildings services, commercial buildings, public health and education establishments, and local communities, particularly through heat networks that link a number of buildings to a circulating heat main.

5 Assessment of Site Suitability

A number of questions should be considered when assessing site suitability for CHP.

What type of building or site is being considered?

CHP units are best suited to applications where there is a significant, constant demand for heating throughout the year. In the public sector, such applications include universities, leisure centres (especially those incorporating swimming pools), hospitals, care homes and multi-residential buildings such as blocks of flats or groups of sheltered housing. Also district or communal heating schemes can be suitable for CHP where there is sufficient diversity of heat demand, perhaps including private sector commercial or industrial heat users. Buildings such as offices, schools, workshops, etc. are rarely suitable for CHP unless grouped with other heat loads due to their relatively intermittent demand for heat. As CHP is a longer-term investment you should consider whether there could be any changes to the building's use within the next 5 to 10 years; CHP needs to have long-term commitment from the user's organisation.

For how many hours in the year is there a steady heat demand?

A good rule of thumb is that for CHP to be viable there should normally be sufficient heat demand for at least 4,500 hours/year and that this should coincide with sufficient electricity demand. You should also consider the quality and resolution of the data you currently have on heat and electricity loads, if this is poor then you may need to undertake some detailed monitoring to ensure your assessment is ultimately robust.

Are there any energy efficiency measures?

Energy efficiency measures such as insulation will reduce the heat load and so change the economics or the appropriate size of CHP. The impact of any likely measures should be factored into the CHP assessment.

What will the fuel be for the CHP system?

If it is natural gas, does the site have a sufficient supply in terms of capacity and pressure? If not an upgrade to the supply would be necessary, adding to project costs. For other fuels, is there sufficient space available for delivery and storage of the fuel on-site?

CHP systems need to be connected to the site's electrical distribution system?

You will need to consider where the connection will be made and at what voltage. Any possible impacts on the public distribution system should also be investigated, irrespective of whether you anticipating export of power or not. Informal discussions with the local Distribution Network Operator should be held once you have an idea of what size of CHP you may wish to install to see whether there are likely to be any major issues or costs that you will need to bear.

Is there insufficient space?

If there is insufficient space in your existing boiler house or access is going to be difficult, building work may be required or an alternative location identified, perhaps even outside in a purpose built weather-proof enclosure. Whilst such issues can usually be resolved, costs can increase as a result. You should also consider whether potential locations might cause noise problems and require additional acoustic abatement, or whether there are any planning requirements.

Are their local planning or air quality restrictions?

Similarly, you will need to consider exhaust and flue arrangements and whether there are any local restrictions regarding air quality that will require special arrangements that will add to project costs.

5.1 Assessing Site Power Loads

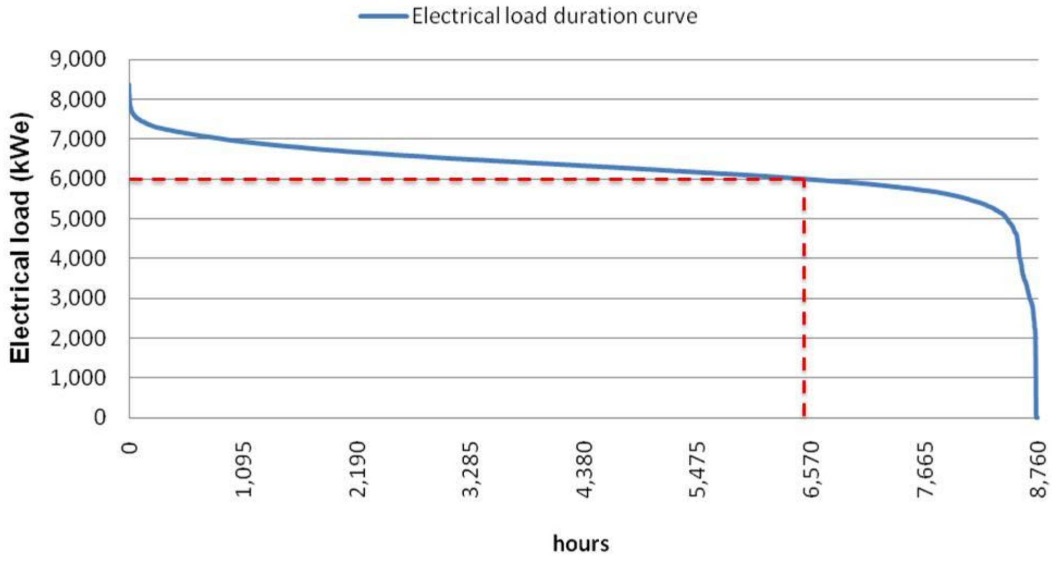
The benefits from a CHP installation are directly related to the number of hours it can operate over a year. This is dependent on the simultaneous demands for both heat and electricity. Ideally the demand information will be based on heat and power consumption measured every hour or every half hour over a complete year.

Information on electricity consumption might be available from the electricity supplier's half-hourly meter readings. This information will require some manipulation and analysis using a spreadsheet package.

Figure 5.1 has been generated from half-hourly meter data over one year. The graph is in the form of a load-duration curve that shows the duration in number of hours for the level of electricity demand.

An electricity demand of at least 6,000kW occurred for a total of around 6,570 hours during the year. This means that an electrical generator with a 6,000kW output could run for a total of 6,570 hours in the year without switching off or modulating down.

Figure 5.1 – Site electrical load



5.2 Assessing Site Heat Loads

Heat demand data are rarely comprehensive and, where information is sparse, some degree of estimation may be required. Monthly fuel bills will provide an indication of seasonal variation. However, for weekly and daily profiles it is helpful to understand the operating pattern of the building or process and to back this up with a short term monitoring exercise. It is important to get as close as reasonably possible to half-hourly consumption figures and to avoid assessing demand from data averaged over long periods.

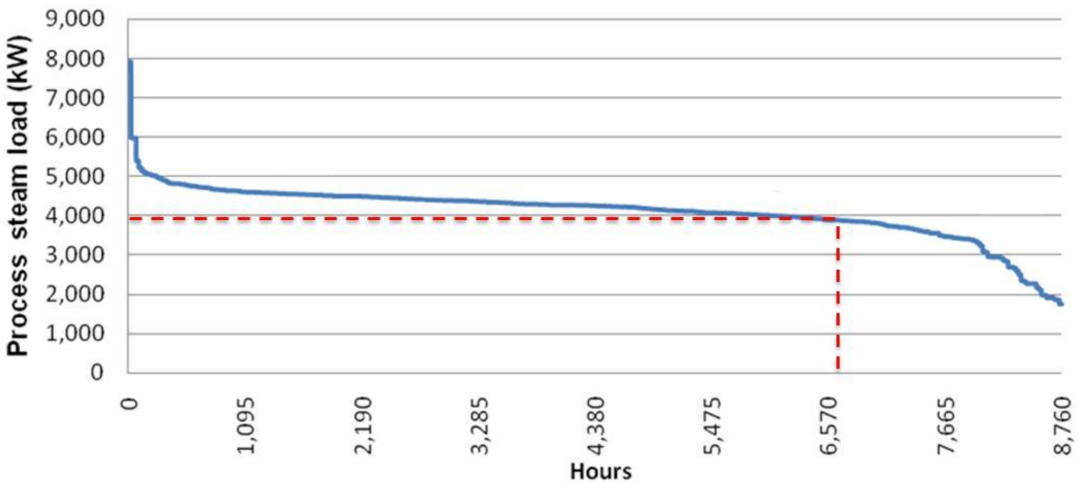
Figure 5.2 shows the heat load duration curve has been generated from daily gas meter readings over one year.

For 6,570 hours operation the heat is a minimum of around 4,000kW from the daily gas data based demand curve. From the electricity load duration curve we saw that this site could accept 6,000kW of electrical generation. However, a CHP system of this size would have a heat to power ratio of around 1.3:1 and so would produce heat at a rate of 7,800 kW, which would be far in excess of the demand for all but a few hours each year. So assuming there is no opportunity to export heat to a neighbour, a CHP at this size would have to reject a significant amount of heat and would be very unlikely to be viable.

An alternative (and arguably better) approach would be to size the CHP based on heat demand. This would lead to a CHP unit with a heat capacity in the region of 4,000kW and a corresponding electrical output of about 3,000kW. In this case this would lead to optimal usage of heat from the CHP and, while the CHP would not met all of the site electrical demand; it would deliver a substantial reduction for electricity taken from the local electricity network.

It is for this reason that it is typically better to size a CHP system on its heat load profile rather than its electrical profile.

Figure 5.2 – Site heat load



5.3 Other Key Considerations

In addition to the issues highlighted at the start of this section, there is a range of other important factors that should be built in as your assessment progresses.

As well as analysis of load durations, it is important to make sure that the electricity and heat loads that you expect the CHP to satisfy actually coincide. If peak electricity and peak heat demands do not coincide then storage of heat may be an option but will introduce additional costs to the scheme.

You also need to consider the suitability of different technologies for providing the grade of heat that the site requires, and making sure that a suitable fit is feasible.

If you have significant cooling loads it may be worth considering whether these can be satisfied via absorption chilling driven by heat from the CHP. Absorption cooling, at its simplest, is a technology that allows cooling to be produced from heat rather than from electricity. This might have the effect of increasing the duration of the heat load and so improve the CHP’s viability. However, such systems are more complex and will require very careful investigation.

The financial savings that a CHP scheme will yield over its lifetime are sensitive to the relative prices of fuel and electricity purchased from the grid. It is important therefore to make sensible judgements about what may happen in the future and what the impact of this would be on the CHP projects viability. Sensitivity analysis can be useful here in understanding the project risks in this regard.

CHP systems are complex and their reliability depends on good planned maintenance. The costs of maintenance are often overlooked by CHP assessments. You should consider routine maintenance such as oil and filter changes to major overhauls.

Whilst it is much simpler to specify CHP based on meeting a proportion of your on-site heat and electricity loads, depending on circumstances there may be overall benefits in specifying a larger system with the purpose of selling electricity and/or heat to other local energy users, or in the case of electricity to an electricity supplier. This is a complex area, but it may at least be worth consideration.

Make sure that measures for the metering and monitoring of CHP energy inputs and outputs necessary for CHPQA certification are included in the scheme design from the outset.

6 Building the Business Case

Table 7.1 provides an illustration of a basic financial analysis of a proposed CHP installation. The left hand column shows the inputs that will have been derived from the analysis of site heat and electricity loads, including the CHP plant specification and the anticipated annual full load equivalent operating hours.

The input financial data include the assumed prices for electricity and fuel, in this case gas and the value of heat, which has been derived from the measured or estimated efficiency of the existing on site boilers. Also shown are the capital cost and the maintenance cost expressed as £ per kWh of electricity generated, these costs will often vary between different CHP system types. Indicative rates can be obtained CHP system suppliers or impartial sources such as the Department of Energy and Climate Change's 'CHP Focus' service[10].

In the right hand column annual energy figures have been calculated by simply multiplying the CHP relevant characteristics in kW by the annual operating hours to give kWh values. These in turn have been multiplied by the electricity, gas and heat unit values. The maintenance cost is similarly calculated and the total annual financial saving derived, which in turn is divided into the CHP capital costs to give the payback period.

Table 7.1 – Basic Financial Analysis of CHP Installation

Plant and Site Characteristics		Annually		
			Energy	Value / Cost
Electrical Output	200kWe	Electricity Generated	1,060,000 kWh	£90,100
Heat Output	300kWth	Useful Heat Generated		£65,720
Fuel Input Rate	580kW	Fuel Used		-£95,294
Electrical Efficiency	34%	Maintenance Cost		-£15,900
Overall Efficiency	86%	Saving		£44,626
Full Load Operation pa	5,300 hours	Payback Period		5.2 years
Imported Electricity Price	0.085 per kWh			
Gas Price	0.031 per kWh			
Existing Boiler Efficiency	75%			
Value of Heat	0.041per kWh			
Capital Cost	£230,000			
Maintenance Cost	£0.015per kWh generated			

A more sophisticated method of financial appraisal is to produce a discounted cash flow for the expected CHP lifetime. This allows the analysis to show the full lifetime benefits and

[10] Please refer to http://chp.decc.gov.uk for more information [accessed 03/05/2017]

factors in the value of money over time. Simple payback takes no account of the ongoing benefits beyond the payback period.

Table 7.2 presents a financial analysis over a 10 year period. Here, to keep things simple, we have assumed that nothing changes over the lifetime of the project. In other words, there is no anticipated change in the annual outputs and performance of the CHP plant, energy prices do not change in real terms, etc. In the bottom row of the table the cash flow for each year is discounted by a rate of 6.0%, which produces a net present value (NPV) of £98,451. The Internal Rate of Return (IRR), which is the discount rate for which the NPV equals zero, is 14.3%.

A discounted cash flow with calculation of the NPV and IRR allows more detailed inclusion of year by year variations in energy prices, carbon allowance prices, loan repayments, significant maintenance events such as major overhauls, etc. Importantly it facilitates sensitivity analysis through varying the assumptions regarding future values, which is important in understanding the project risks.

Table 7.2 – Financial Analysis of CHP Installation over 10 years

Discount rate	6.0%
Existing boiler efficiency	75%

Discount factor	1.0000	0.9434	0.8900	0.8396	0.7921	0.7473	0.7050	0.6651	0.6274	0.5919	0.5584

Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Capital	-£230,000										
Electricity generated, kWh		1,060,000	1,060,000	1,060,000	1,060,000	1,060,000	1,060,000	1,060,000	1,060,000	1,060,000	1,060,000
Useful heat generated, kWh		1,590,000	1,590,000	1,590,000	1,590,000	1,590,000	1,590,000	1,590,000	1,590,000	1,590,000	1,590,000
Fuel used, kWh		3,074,000	3,074,000	3,074,000	3,074,000	3,074,000	3,074,000	3,074,000	3,074,000	3,074,000	3,074,000
Grid electricity price per kWh		£ 0.085	£ 0.085	£ 0.085	£ 0.085	£ 0.085	£ 0.085	£ 0.085	£ 0.085	£ 0.085	£ 0.085
Gas price per kWh		£ 0.031	£ 0.031	£ 0.031	£ 0.031	£ 0.031	£ 0.031	£ 0.031	£ 0.031	£ 0.031	£ 0.031
Routine maint' cost/kWh elec		£ 0.015	£ 0.015	£ 0.015	£ 0.015	£ 0.015	£ 0.015	£ 0.015	£ 0.015	£ 0.015	£ 0.015
Value of electricity generated		£90,100	£90,100	£90,100	£90,100	£90,100	£90,100	£90,100	£90,100	£90,100	£90,100
Value of heat generated		£65,720	£65,720	£65,720	£65,720	£65,720	£65,720	£65,720	£65,720	£65,720	£65,720
Cost of fuel		-£95,294	-£95,294	-£95,294	-£95,294	-£95,294	-£95,294	-£95,294	-£95,294	-£95,294	-£95,294
Routine maintenance cost		-£15,900	-£15,900	-£15,900	-£15,900	-£15,900	-£15,900	-£15,900	-£15,900	-£15,900	-£15,900
Simple cash flow	-£230,000	£44,626	£44,626	£44,626	£44,626	£44,626	£44,626	£44,626	£44,626	£44,626	£44,626
Discounted cash flow	**-£230,000**	**£42,100**	**£39,717**	**£37,469**	**£35,348**	**£33,347**	**£31,460**	**£29,679**	**£27,999**	**£26,414**	**£24,919**

NPV	**£98,451**
IRR	**14.3%**

A discounted cash flow (DCF) allows more detailed inclusion of year by year variations in factors such as:

- CHP running hours due to expected changes in site opening hours;
- Energy prices;
- Carbon allowance prices;
- Loan repayments; and
- Significant maintenance events such as major overhauls.

In Table 7.3, it is assumed that the real price of electricity and gas will increase annual by 1.5% and 1.0% respectively (i.e. over and above the level of general inflation). Also we have added a major plant overhaul in year 4 and 8. Overall the result is a higher NPV of £116,836 and IRR of 15.4% due to the increased difference between electricity and gas prices, which is sometimes referred to as the spark spread.

Importantly, a DCF (DCF) analysis facilitates sensitivity analysis through varying the assumptions regarding future values, which is important in understanding the project risks.

Table 7.3 – Financial Analysis of CHP Installation over 10 years

Discount rate	6.0%
Existing boiler efficiency	75%

Real pa increase in electricity prices	1.5%
Real pa increase in gas prices	1.0%

Year	0	1	2	3	4	5	6	7	8	9	10
Discount factor	1.0000	0.9434	0.8900	0.8396	0.7921	0.7473	0.7050	0.6651	0.6274	0.5919	0.5584
Capital	-£230,000										
Electricity generated, kWh		1,060,000	1,060,000	1,060,000	1,060,000	1,060,000	1,060,000	1,060,000	1,060,000	1,060,000	1,060,000
Useful heat generated, kWh		1,590,000	1,590,000	1,590,000	1,590,000	1,590,000	1,590,000	1,590,000	1,590,000	1,590,000	1,590,000
Fuel used, kWh		3,074,000	3,074,000	3,074,000	3,074,000	3,074,000	3,074,000	3,074,000	3,074,000	3,074,000	3,074,000
Grid electricity price per kWh		£ 0.085	£ 0.086	£ 0.088	£ 0.089	£ 0.090	£ 0.092	£ 0.093	£ 0.094	£ 0.096	£ 0.097
Gas price per kWh		£ 0.031	£ 0.031	£ 0.032	£ 0.032	£ 0.032	£ 0.033	£ 0.033	£ 0.033	£ 0.034	£ 0.034
Routine maint' cost/kWh elec		£ 0.015	£ 0.015	£ 0.015	£ 0.015	£ 0.015	£ 0.015	£ 0.015	£ 0.015	£ 0.015	£ 0.015
Value of electricity generated		£90,100	£91,452	£92,823	£94,216	£95,629	£97,063	£98,519	£99,997	£101,497	£103,019
Value of heat generated		£65,720	£66,377	£67,041	£67,711	£68,388	£69,072	£69,763	£70,461	£71,165	£71,877
Cost of fuel		-£95,294	-£96,247	-£97,209	-£98,182	-£99,163	-£100,155	-£101,157	-£102,168	-£103,190	-£104,222
Routine maintenance cost		-£15,900	-£15,900	-£15,900	-£15,900	-£15,900	-£15,900	-£15,900	-£15,900	-£15,900	-£15,900
Major plant overhaul					-£10,000				-£10,000		
Simple cash flow	-£230,000	£44,626	£45,682	£46,755	£37,845	£48,954	£50,081	£51,226	£42,390	£53,573	£54,775
Discounted cash flow	**-£230,000**	**£42,100**	**£40,657**	**£39,256**	**£29,977**	**£36,581**	**£35,305**	**£34,068**	**£26,596**	**£31,710**	**£30,586**

NPV	**£116,836**
IRR	**15.4%**

5 Further Useful Links and Documents

Title	Source	Description	Link
Renewable energy sources - Opportunities for businesses	The Carbon Trust	Introduces the main sources of renewable energy and helps readers to assess whether renewable energy is a viable option for their business	www.carbontrust.com/media/7379/ctv010_-_renewable_energy_sources.pdf
Power play - Applying renewable energy technologies to existing buildings	The Carbon Trust	Provides advice and tips to help plan, build and manage cost-effective low carbon buildings	www.carbontrust.com/media/81373/ctg050-power-play-renewable-energy-technologies-existing-buildings.pdf
Introducing combined heat and power - A new generation of energy and carbon savings	The Carbon Trust	Provides an overview of CHP technology	www.carbontrust.com/media/19529/ctv044_introducing_combined_heat_and_power.pdf
Feed-in Tariff - About the Scheme and How to Apply	OFGEM	Provides an overview of the Feed-in tariff scheme	www.ofgem.gov.uk/ofgem-publications/85793/fitfactsheetjan14.pdf
Combined Heat and Power Association	CHPA	The Combined Heat and Power Association (CHPA) is the leading advocate of an integrated approach to delivering energy services using combined heat and power and district heating and cooling	www.chpa.co.uk
CHP Focus	DECC	CHP Focus is a DECC initiative to support the development of combined heat and power in the UK. On the website can be found comprehensive information on all aspects of cogeneration, whether you are new to CHP or looking for specific information There is also free helpline support provided on 0845 365 5153, where experts can provide guidance to those who require it	www.gov.uk/combined-heat-and-power