Combined Heat and Power Association

Time to Take a Fresh Look at CHP...

Dr Simon MINETT, Director,

DELTA Energy and Environment

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Dennenboslaan 26, 3090 Overijse, Belgium
Tel +32 477 544 095; Fax +32 2 772 50 44;
Email simon.minett@delta-ee.com; Web www.delta-ee.com

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COMBINED HEAT AND POWER ASSOCIATION

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Dennenboslaan 26, 3090 Overijse, Belgium
Tel +32 477 544 095; Fax +32 2 772 50 44;
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INTRODUCTION

The CHPA is re-evaluating the benefits of CHP in the face of UK Government scepticism as to the benefits of the use of CHP. This issue has been fuelled by the problems the CHP sector has faced over the recent years with a very tough commercial environment and the simple fact that Government responsibility for CHP is with Defra and all other energy policy is with DTI. In recent modelling assessments undertaken by the DTI CHP has been shown in a very unfavourable light and with the DTI concluding that the benefits of CHP are very limited and questioning the need to support CHP development assuming that the market will build CCGTs. It is also true that over the same timeframe of the last 6 years only one CCGT project has been contracted in mainland UK and none are presently under construction.

This study has investigated the impact of CHP for environmental impacts and benefits.

BASICS

CHP has long been recognised as a technique that reduced the energy consumption required to supply heat and power. Principally, most CHP plants produce electricity and heat, in the form of hot water or steam. However, CHP can also produce mechanical power, cooling through absorption chillers from the heat output and other heat outputs, such as thermal oil and the direct use of the exhaust gases. Attendant with the reductions of energy use come other benefits, such as reductions in emissions and especially carbon dioxide.

The degree of energy and carbon savings will depend on the technology and fuel used in the CHP scheme and on the alternatives displaced. The characteristics of a CHP scheme are well defined, so the main uncertainty in assessing carbon savings is in the fuel and efficiency assumed for alternative sources of the heat and power displaced. For practical purposes, certain conventions must be adopted to calculate carbon savings, particularly for portfolios of schemes. The choice of convention, and the assumption to be made regarding fuel and efficiency for alternative sources, will be determined by the purpose and scope of the calculation and whether the savings are to be assessed now or into the future.

A CHP scheme is installed to meet a heat demand, either existing or new, that would otherwise be provided by boilers, along with an economic electricity supply. Existing boilers have well-known characteristics and it is relatively straightforward to calculate avoided emissions. Where the heat demand is new or the existing boiler has reached the end of its lifetime, it may be more appropriate to calculate the avoided emissions based on the characteristics of a new boiler. There are now very limited possibilities to improve the efficiency of new boilers.

THE CURRENT UK GOVERNMENT COMPARISON

The current views of the benefits of CHP were presented in a paper in Energy Trends in the summer of 2003. The paper was prepared by Future Energy Solutions (FES) for the DTI. In various meetings of the members of CHPA and the staff of the CHPA, this paper has been discussed.

The initial conclusions from this paper are that the analysis is not transparent, that the choices made in the analysis tend to discriminate against CHP and that the overall conclusions underestimate the benefits of CHP.

The paper concludes with an assessment of the savings in terms of carbon from CHP of 0.7 MtC per 1000 MWe installed in the short term reducing to just 0.1 MtC per 1000 MWe as CHP displaces new CCGT plant.

INSERTS FROM ENERGY TRENDS

Table 5 Annual emissions savings from new CHP installed to meet the Government target of 10 GWe installed capacity

Scenario 1 – in the short term			
	Output (GWh)	Emissions factor (gC/kWh)	Carbon emissions (MtC)
Equivalent emissions from electricity	27,331	190	5.2
Equivalent emissions from heat	39,175	80	3.1
Emissions from CHP			4.6
Savings			3.8
Savings per 1,000MWe			**0.7**

Table 6 Annual emissions savings from new CHP installed to meet the Government target of 10 GWe installed capacity

Scenario 2 – towards 2010			
	Output (GWh)	Emissions factor (gC/kWh)	Carbon emissions (MtC)
Equivalent emissions from electricity	27,331	111	3.0
Equivalent emissions from heat	39,175	56	2.2
Emissions from CHP			4.6
Savings			0.7
Savings per 1,000MWe			**0.1**

It is not the intention of this paper to re-calculate the FES results, but to represent the data in a much more transparent manner, so that a proper debate can be undertaken.

As a general comment the approach that presents the benefits of CHP in terms of MtC per 1000 MWe installed is also somewhat misleading, as this does not provide information on technologies and usage. It would be better to present the data in terms of kg/MWh of electricity produced and this is presented in the results.

THE MODELLING APPROACH

This study is based on a series of spreadsheets, which develop the analysis of the benefits of CHP. The spreadsheet model is not presented with this report, but is available to the CHPA and can be reviewed should this be necessary. The approach has been to make the whole analysis as open and transparent as possible. This will allow a more productive debate on the benefits accruing from CHP. The aim is to provide a realistic assessment of CHP and its alternatives.

For the analysis five CHP schemes have been analysed. These are:

- 1 kWe domestic CHP plant for a single-family house;
- 1 MWe gas engine CHP scheme in a public sector building, a hospital;
- 9.6 MWe gas turbine CHP scheme in the food industry;
- 41.6 MWe gas turbine CHP scheme in the chemicals industry;
- 350 MWe CCGT CHP scheme in oil refining.

These are designed to be representative of the range of CHP schemes seen in the UK. In each case actual data have been obtained from similar plants, which have then been adapted to present more generalised schemes. The key data for each of these schemes is given in Annex 1.

All calculations in the study have been undertaken using the Gross Calorific Value (Higher Heating Value) of the fuel. This approach is consistent with the methods used in the UK, but is not consistent with European conventions and the CHP Directive, which use Net Calorific Value (Lower Heating Value). Note this has no effect on carbon emissions or carbon savings, only on reported efficiencies.

CHP performance has been compared with reference power plants and boiler plants. Here two alternative approaches have been adopted:

- **Avoided Investment Approach**. This is a comparison with new investments in the electricity and heating. CHP investments are compared against the next power sector investment, a CCGT of 410 MWe block size. The CHP also displaces investment in new boilers for the same heat output as the CHP plants.

- **Most Likely Displacement Approach**. This comparison compares the CHP plants with the average fossil fuel fired electricity production on the UK electricity system and older and therefore less efficient boiler plants.

In both cases the data used are taken from published sources, especially the Digest of United Kingdom Energy Statistics and the web-site of VGB Power Tech e.V., the German power plant operators association, which publishes data on power station performance.

The key data are presented below, with more details given in Annex 2 and Annex 3:

- A CCGT power plant with a manufacturer rated efficiency of 52.5% (57.7% LHV), which is based on the Siemens SCC5-4000F. The efficiency of this power station is then adjusted downwards to take account of expected peak performance in operation, in house loads and degradation over time. For baseload operation the annual efficiency is 48.7%. If the CCGT is not run baseload then the efficiency is lower than baseload operation. This is because of the increased number of stops and starts, ramping from part-load to full-load and sub-optimal operation. Thus mid-merit CCGT operation has an efficiency of 46.2% (95% of the efficiency of baseload operation) and peak load operation is 43.8% (90% of the efficiency of baseload operation).

- A sensitivity run has been undertaken taking the claimed efficiency of a GE H-class CCGT of 54.6% (60% LVH). However, this technology is beset with operational problems and thus is as yet unproven operationally. If 54.6% was achieved then the baseload efficiency would be 50.6%, but the off-baseload performance suffers more greatly than for less efficient machines. In this case mid-merit efficiency would be 47.1% (93% of the efficiency of baseload operation) and peak load operation is 44.5% (88% of the efficiency of baseload operation). It should be stressed that these data are not measured as there is still no field data for the H-class CCGT.

- The delivered efficiency of electricity from the power plant to the site on which the CHP plants are located is adjusted to take account of grid losses. The average grid loss in the UK was 8.7% in 2003. However, this does not give any indication of the real delivered efficiency. Data from COGEN Europe on theoretical grid losses has been used. This approach estimates the losses that occur at different voltage levels in the electricity system, looking at both transformer losses and heating losses on the wires. Thus for customers connected at high voltage the grid losses are 2.6%, at medium voltage the losses are 6.4% and at low voltage 12.2%.

- Where a CHP plant only displaces imported electricity then the grid losses for that voltage level are incorporated in the delivered electricity efficiency. Where the CHP plants also exports electricity to the network, then the exported electricity is assumed to displace the power station and the losses on the grid for the next voltage level up from the connection. Thus a CHP plant situated in the low voltage network displaces grid losses of 12.2% for the power consumed on site and 6.4% for power exported from site.

- The current efficiency of CCGTs in the UK is 46.4%, excluding own use according to DUKES (2004), giving an average electricity supplied efficiency of around 44%.

- The fossil fuel mix comprises 49.6% coal, 49.7% gas and 0.7% oil, with an overall efficiency of 38.8%. It excludes the role of nuclear power and renewable energy sources. In practice nuclear and renewables are unlikely to be displaced by CHP generation: existing fully depreciated nuclear is a low cost generator and renewables are subjected to obligations. In both cases this will entail these sources to be “dispatched” in preference to all other generators.

- The reference boilers for displaced investment are adjusted for load factor and cycling. Typically boilers lose between 5 and 15% of their efficiency on an annual basis due to these factors. The boiler efficiencies used are: 88.5% for

Dennenboslaan 26, 3090 Overijse, Belgium
Tel +32 477 544 095; Fax +32 2 772 50 44;
Email simon.minett@delta-ee.com; Web www.delta-ee.com

domestic condensing boilers; 75.3% of the boilers in the hospital; 73.7% for the industrial boilers in the food industry case and 72.1% for the boilers in the chemicals and oil refinery cases.

- The older boilers are less efficient than new boiler investments. There is conflicting data available on these boiler performances. Discussions with some operators in the course of this study and data from VIK in Germany and the CEA in the UK indicate that operation old boilers are generally slightly less efficient than new investments. For the domestic sector it is assumed that the old boiler is more than 15 years old, non-condensing and oversized, which is typical of the UK. This boiler has an annual efficiency of 60%. For the hospital the boiler is 75% efficient and in industry all boilers are 73% efficient. There is a very wide variation on these numbers.
- Carbon emissions are based on the carbon content of the fuel and are based on DUKES and other sources. It is assumed that refinery gases have a carbon emission 15% less than natural gas. The carbon emissions from each source, be it power, heat or CHP, is a factor of the carbon content of the fuel and the efficiency of the cycle.

RESULTS

The results of the study are presented in the following tables. The discussion is kept short and only highlights the key points.

Technical specifications of the CHP plants:

Size	**1 kWe**	**1 MWe**	**10 MWe**	**50 MWe**	**350 MWe**
Sector	Domestic	Hospital	Food	Chemicals	Oil Refining
Technology	Stirling Engine	Gas Engine	Gas Turbine	Gas Turbine and Steam Turbine	CCGT
Heat Output	Hot Water	Hot Water	Steam	Steam	Steam
Heat to Power Ratio	6.67:1	1.24:1	1.56:1	1.18:1	1.07:1
Main Fuel	Natural Gas	Natural Gas	Natural Gas	Natural Gas	Natural Gas
Share	100%	100%	98%	98%	75%
Secondary Fuel	none	none	Gas Oil	Gas Oil	Refinery Gases
Operational hours / year	3000	5500	7000	8200	8300
Electricity used on site	80%	100%	100%	75%	10%
Electricity Exported	20%	0%	0%	25%	90%
Total Capital Cost	£2615	£637500	£7.67 m	£40.53 m	£220 m

Summary of CHP Operation:

Size	1 kWe	1 MWe	10 MWe	50 MWe	350 MWe
Electrical Capacity (MWe)	0.0009	1.2	9.6	54.0	350
Heat Capacity (MWt)	0.006	1.4	15.0	63.8	375
Hours of operation (h/a)	3000	5500	7000	8200	8300
Electricity Production (MWh)	2.7	6353	62300	415740	2822000
Electricity Export (MWh)	0.5	0	0	103935	2539800
Heat Production (MWh)	18.0	7920	105000	522750	3112500
Fuel Consumption (MWh)	22.8	18210	230677	1314591	5985577
Efficiency of Use (%)	90.7%	78.5%	74.6%	73.6%	75.4%
Carbon Emissions (tC/a)	1.14	909	11596	66081	360237

Avoided Investment Approach:

Basis for Comparison

In the standard case the power station displaced is a new investment in a CCGT. However, for the large CHP schemes that run continuously the displacement is against a CCGT running baseload. For the hospital and small industrial CHP schemes these are assumed to displace mid-merit CCGT operation. Finally the domestic CHP is assumed to displace a CCGT running in peaking duty.

Size	1 kWe	1 MWe	10 MWe	50 MWe	350 MWe
Power Plant Displaced	CCGT Peak	CCGT Mid-Merit	CCGT Mid-Merit	CCGT Baseload	CCGT Baseload
Efficiency (%)	43.8%	46.2%	46.2%	48.7%	48.7%
Grid Losses for Imports	12.2%	6.4%	6.4%	6.4%	2.6%
Imported Efficiency (%)	38.5%	43.3%	43.3%	45.6%	47.4%
Grid losses for Exports	6.4%	6.4%	2.6%	2.6%	0.0%
Exported Efficiency (%)	41.0%	43.3%	45.0%	47.4%	48.7%
Boiler Efficiency (%)	88.5%	80.2%	76.9%	75.2%	75.2%

Energy Savings

The energy savings calculations are based on the avoided electricity imported from the grid, displaced electricity for any export and the use of boiler plant for the heat provision. These are compared with the fuel consumed by the plant and the savings are then calculated. All data are for annual operation.

Size	1 kWe	1 MWe	10 MWe	50 MWe	350 MWe
Displaced Fuel for Imported Electricity (MWh)	5.6	14678	143953	684444	595290
Displaced Fuel for Exported Electricity (MWh)	1.3	0	0	219247	5218315
Displaced Boiler Fuel (MWh)	20.6	9849	136588	698160	4165022
Total Displaced Fuel (MWh)	27.5	24527	280540	1601851	9978627
CHP Fuel (MWh)	22.8	18210	230677	1314591	7481971
Savings (MWh)	4.7	6316	49864	287260	2496656
% Savings against References	17.0%	25.8%	17.8%	17.9%	25.0%
Savings per MWe installed per year (MWh)	5191	5445	5194	5320	7133

It can be seen that the energy savings from CHP range from 17% to 26%, and are in the range of 5200-7100 MWh per MW of installed capacity per year.

Carbon Savings

Size	1 kWe	1 MWe	10 MWe	50 MWe	350 MWe
Emission from CHP (tC/a)	1.14	909	11596	66081	360237
Emissions from Electricity (tC/a)	0.35	733	7185	45102	290152
Emissions from Boilers (tC/a)	1.03	492	6817	34845	207872
Carbon Savings (tC/a)	0.23	315	2406	13866	137788
% Saving against references	17%	26%	17%	17%	28%
Carbon Savings per MWe per year (tC/a)	259	272	251	257	394
Savings per 1000 MWe (MtC)	0.26	0.27	0.25	0.26	0.39
Carbon Savings (kg/MWhe)	86.4	49.6	38.6	33.4	48.8

The carbon savings are substantial and much greater than those calculated in the FES report. Carbon savings are between 0.25 MtC and 0.40 MtC per 1000 MWe installed per year. The carbon savings are affected by the hours of operation of the various schemes and this is dependent on the heat demand and the seasonal nature of space heating. The upper carbon saving is increased due in part by the fact that the oil refinery burns refinery off gases. These have a lower carbon content than natural gas and also displace a small amount of flaring, typically between 1 and 5%.

Most Likely Displacement Approach

The same analysis is undertaken for CHP displacing the most likely mix of plants; that is the fossil fuel mix for the power sector and an older boiler on site.

Basis for Comparison

Size	1 kWe	1 MWe	10 MWe	50 MWe	350 MWe
Power Plant Displaced	Fossil Fuel Mix	Fossil Fuel Mix	Fossil Fuel Mix	Fossil Fuel Mix	Fossil Fuel Mix
Efficiency (%)	38.8%	38.8%	38.8%	38.8%	38.8%
Grid Losses for Imports	12.2%	6.4%	6.4%	6.4%	2.6%
Imported Efficiency (%)	34.1%	36.3%	36.3%	36.3%	37.8%
Grid losses for Exports	6.4%	6.4%	2.6%	2.6%	0.0%
Exported Efficiency (%)	36.3%	36.3%	37.8%	37.8%	38.8%
Boiler Efficiency (%)	60.0%	75.0%	73.0%	73.0%	73.0%

Energy Savings

Size	1 kWe	1 MWe	10 MWe	50 MWe	350 MWe
Displaced Fuel for Imported Electricity (MWh)	6.3	17492	171549	858586	1089163
Displaced Fuel for Exported Electricity (MWh)	1.5	0	0	275030	9547603
Displaced Boiler Fuel (MWh)	30.3	10533	143836	719178	4290411
Total Displaced Fuel (MWh)	38.2	28026	315385	1852793	11583160
CHP Fuel (MWh)	22.8	18210	230677	1314591	7481971
Savings (MWh)	15.3	9815	84708	538202	4101189
% Savings against References	40.2%	35.0%	26.9%	29.0%	35.4%
Savings per MWe installed per year (MWh)	17042	8461	8824	9967	11718

In this case where the displaced power is the fossil fuel mix, supplied at lower efficiency than the best new investment case and old boilers then the energy savings almost double. In reality this case is the most likely scenario for real savings from CHP. This is because it is unlikely that the most modern investment will be displaced, but something that already exists.

Dennenboslaan 26, 3090 Overijse, Belgium
Tel +32 477 544 095; Fax +32 2 772 50 44;
Email simon.minett@delta-ee.com; Web www.delta-ee.com

Carbon Savings

Size	1 kWe	1 MWe	10 MWe	50 MWe	350 MWe
Emission from CHP (tC/a)	1.14	909	11596	66081	360236
Emissions from Electricity (tC/a)	0.54	1217	11931	78839	739749
Emissions from Boilers (tC/a)	1.51	526	7179	35894	214131
Carbon Savings (tC/a)	0.92	833	7514	48651	361079
% Saving against references	45%	48%	39%	42%	50%
Carbon Savings per MWe per year (tC/a)	1021	718	783	901	1032
Savings per 1000 MWe (MtC)	1.02	0.72	0.78	0.90	1.03
Carbon Savings (kg/MWhe)	340.4	131.2	120.6	117.0	128.0

Once again it can be seen that there are substantial carbon savings from CHP. In this case they are more than double the savings in the avoided investment approach.

SENSITIVITY ANALYSIS

GE H-Class CCGT

A sensitivity analysis was undertaken to look at the impact of increased efficiency, if achieved, of the introduction of the GE H-class CCGT. Here a simplified table is presented with only the new data and results.

Basis for Comparison

Size	1 kWe	1 MWe	10 MWe	50 MWe	350 MWe
Power Plant Displaced	CCGT Peak	CCGT Mid-Merit	CCGT Mid-Merit	CCGT Baseload	CCGT Baseload
Efficiency (%)	44.5%	47.1%	47.1%	50.6%	50.6%
Grid Losses for Imports	12.2%	6.4%	6.4%	6.4%	2.6%
Imported Efficiency (%)	39.1%	44.1%	44.1%	47.4%	49.3%
Grid losses for Exports	6.4%	6.4%	2.6%	2.6%	0.0%
Exported Efficiency (%)	41.7%	44.1%	45.8%	49.3%	50.6%
Boiler Efficiency (%)	88.5%	80.2%	76.9%	75.2%	75.2%

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Email simon.minett@delta-ee.com; Web www.delta-ee.com

Energy Savings

Size	1 kWe	1 MWe	10 MWe	50 MWe	350 MWe
Displaced Fuel for Imported Electricity (MWh)	5.5	14419	141411	658207	572471
Displaced Fuel for Exported Electricity (MWh)	1.3	0	0	210843	5018279
Displaced Boiler Fuel (MWh)	20.6	9849	136585	698160	4165022
Total Displaced Fuel (MWh)	27.4	24268	277999	1567209	9755772
CHP Fuel (MWh)	22.8	18210	230677	1314591	7481971
Savings (MWh)	4.6	6057	47322	252618	2273801
% Savings against References	16.6%	25.0%	17.0%	16.1%	23.3%
Savings per MWe installed per year (MWh)	5064	5222	4929	4678	6497

Carbon Savings

Size	1 kWe	1 MWe	10 MWe	50 MWe	350 MWe
Emission from CHP (tC/a)	1.14	909	11596	66081	360237
Emissions from Electricity (tC/a)	0.34	720	7058	43373	279029
Emissions from Boilers (tC/a)	1.03	492	6817	34845	207872
Carbon Savings (tC/a)	0.23	302	2279	12137	126665
% Saving against references	17%	25%	16%	16%	26%
Carbon Savings per MWe per year (tC/a)	253	261	237	225	362
Savings per 1000 MWe (MtC)	0.25	0.26	0.24	0.22	0.36

The higher efficiency of the CCGT plants delivers some reductions in both energy savings and carbon reductions. Overall this reduction is around 1% point.

Note: For a fair comparison the CCGT technology should be fully commercial and proven, not based on field trails or laboratory data. The principle should be based on an alternative option to CHP that must be economically justified. In the industrial sector this means that novel plant options are never installed without special arrangements with the supplier of the equipment. A plant, be it utility or process, is not deemed to be fully commercial until it has achieved 3 years of operation in the field. The same principle must also apply to a competitive electricity industry, where the risk of equipment failure is borne fully by the operating company. Thus, new technology such as the GE H-class CCGT is not yet fully commercial and should not be included as a reference technology.

CONCLUSIONS

The modelling has shown that CHP provides substantial energy and carbon reductions. When comparing with the avoided investment approach of a high efficiency CCGT and new boilers CHP saves in the range of 17-26% energy consumption, dependent on the size plant. The carbon savings are in the range of 0.25-0.4 MtC per 1000 MWe of CHP installed per year. This is far greater than the estimates given by FES in 2003 of 0.1 MtC per 1000 MWe per year.

Under the most likely displacement approach CHP saves in the range 27-40% of energy consumption and reduces carbon emissions by between 0.72 and 1.03 MtC/a per 1000 MWe installed. This again is greater than the saving given in the FES paper of 0.7 MtC per 1000 MWe per year.

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Email simon.minett@delta-ee.com; Web www.delta-ee.com

ANNEX 1: DATA ON CHP SCHEMES

INSTALLATION DATA FOR CHP PLANTS

SIZE CASE		1 kWe	1 MWe	10 MWe	50 MWe	350 MWe
Description of the CHP Installation						
CHP Description		Domestic CHP	Gas Engine CHP	Gas Turbine CHP	Gas Turbine CHP	CCGT CHP
Prime Mover Type		Stirling Engine	Gas Engine	Gas Turbine	Gas Turbine	Gas Turbine
Heat Recovery Type		Heat Exchanger	Heat Exchanger	Unfired-WHB	Fired HRSG	Fired HRSG
Additional Prime Mover		No	No	No	Steam Turbine	Steam Turbine
Heat Provision Grade		Hot Water	Hot Water	10 bar Steam	7 bar & 2 bar	40 bar & 10 bar
Primary Fuel		Natural Gas	Natural Gas	Natural Gas	Natural Gas	Natural Gas
Secondary Fuel		None	None	Gas Oil	Gas Oil	Refinery Wastes
Gas supply pressure		Atmosphere	Atmosphere	Atmosphere	Medium Pressure	NTS
Compression of Fuel		No	No	Yes	Yes	No
Connection Voltage		230 V	440 V	6.6 kV	11 kV	132 kV
Location and use						
Top Sector		Residential	Public	Industry	Industry	Industry
Branch		Family House	Hospital	Food	Chemicals	Oil Refining
Technical characteristics of the CHP Installation						
Electrical output capacity	MW	0.001	1.2	9.6	54.0	350.0
Gas Compression and in-house loads	MW	0.000	0.0	0.7	3.3	10.0
Net Electrical Output	MW	0.001	1.2	8.9	50.7	340.0
Thermal output capacity	Tonnes				85.0	500.0
Thermal output capacity	MW	0.006	1.4	15.0	63.8	375.0
Electrical efficiency (LHV)	%	13.0%	38.5%	32.0%	37.0%	40.0%
Thermal efficiency (LHV)	%	86.7%	47.8%	50.0%	43.7%	42.9%
Total efficiency (LHV)	%	99.7%	86.3%	82.0%	80.7%	82.9%
Electrical efficiency (HHV)	%	11.8%	35.0%	29.1%	33.7%	36.4%
Thermal efficiency (HHV)	%	78.9%	43.5%	45.5%	39.7%	39.0%
Total efficiency (HHV)	%	90.7%	78.5%	74.6%	73.4%	75.4%
Power to heat ratio		0.15	0.81	0.64	0.85	0.93
Heat to power ratio		6.67	1.24	1.56	1.18	1.07
Fuel Consumption per hour	MW	0.0076	3.31	32.97	160.38	961.54
Share of Primary Fuel	%	100%	100%	98%	98%	75%
Primary Fuel Consumption	MW	0.0076	3.31	32.31	157.17	721.15
Share of Secondary Fuel	%	0%	0%	2%	2%	25%
Secondary Fuel Consumption	MW	0.0000	0	0.65	3.14	180.29

Dennenboslaan 26, 3090 Overijse, Belgium
Tel +32 477 544 095; Fax +32 2 772 50 44;
Email simon.minett@delta-ee.com; Web www.delta-ee.com

INSTALLATION DATA FOR CHP PLANTS

SIZE CASE		1 kWe	1 MWe	10 MWe	50 MWe	350 MWe
Operational data						
Hours of operation per year	hr/yr	3000	5500	7000	8200	8300
Full-load load factor	%	34.25%	62.79%	79.91%	93.61%	94.75%
Electricity on-site consumption	%	80%	100%	100%	75%	10%
Electricity Production	MWh	2.700	6353	62300	415740	2822000
Heat Production	MWh	18.000	7920	105000	522750	3112500
Primary Fuel Consumption	MWh	22.823	18210	226154	1288815	5985577
Secondary Fuel Consumption	MWh	0.000	0	4523	25776	1496394
Total Fuel Consumption	MWh	22.823	18210	230677	1314591	7481971
Electricity Used on-site	MWh	2.160	6353	62300	311805	282200
Electricity Exported	MWh	0.540	0	0	103935	2539800
Capital Costs						
Total Cost of Equipment	£/kWe	1350	400	800	700	450
Installation Fixed Cost	£	1400	60000	100000	2500000	50000000
Connection Cost	£					
Installation Variable Cost	£/kWe	0	100	50	50	50
Operational Costs						
Variable Maintenance Costs	p/kWh	0	0.56	0.45	0.4	0.3
Fixed Maintenance Costs	£	170	1000	5000	10000	50000
Carbon Emissions						
Primary Fuel	tC	1.14	908.86	11287.13	64323.58	298734.70
Secondary Fuel	tC	0.00	0.00	308.39	1757.47	61501.80
Total	tC	1.14	908.86	11595.52	66081.06	360236.51

Key: Cells in these tables that are coloured light blue are input data and cells coloured yellow are calculations.

The data have been supplied by various CHP operators in the CHPA and thanks are given to them, though the names of the companies are not released to protect commercial interests. (The full-load load factor is the MWh of power generated divided by the plate rated capacity times the hours in the year.)

The CHPA and DELTA Energy and Environment are keen to ensure that the input data is correct and thus any comments or new data sets are welcome.

Dennenboslaan 26, 3090 Overijse, Belgium
Tel +32 477 544 095; Fax +32 2 772 50 44;
Email simon.minett@delta-ee.com; Web www.delta-ee.com

ANNEX 2: DATA REFERENCE PLANTS (AVOIDED INVESTMENT APPROACH)

Base case power data

REFERENCE POWER PLANT DATA

Reference Power Plant for Avoided Investment			
Combined Cycle Gas Turbine		Siemens SCC5 4000F	
Size of Station	MW	410	
Primary Fuel		Natural Gas	
Secondary Fuel		Gas Oil	
Gas supply pressure		High Pressure	
Compression of Fuel		Yes	
Connection Voltage		200 kV	
Reference Power Plant Capital Investment			
CCGT Capital Cost	£/kWe	350	
CCGT Capital Cost	£ million	143,5	
Installation cost	£ million	14,4	10%
Grid Connection - shallow	£ million	5,0	
Total Costs	£ million	162,9	
Technical characteristics CCGT			
Design electrical efficiency LHV	%	57,70%	
Design electrical efficiency HHV	%	52,51%	
Design electrical output capacity	MW	410,0	
Thermal output capacity	MW	0,0	0%
Fuel Consumption at full load	MW	780,8	
Actual best electrical output at generator terminals	MW	397,7	50,9%
Inhouse loads	MW	9,7	2,4%
Degradation of CCGT over year	MW	8,0	2,0%
Net electrical output	MW	380,0	
Net electrical efficiency (HHV)	%	48,7%	
Annual electrical efficiency - baseload		48,7%	
Annual electrical efficiency - mid-merit		46,2%	95%
Annual electrical efficiency - peaking		43,8%	90%
Share of Primary Fuel	%	100%	
Primary Fuel Consumption	MW	780,8	
Share of Secondary Fuel	%	0%	
Secondary Fuel Consumption	MW	0,0	
Operational Data			
Variable operation and maintenance cost	p/kWh	0,3	
Fixed O&M	£/a	50000	
Labour used on CCGT power station			
Staff Employed for Baseload	N°	45	
Staff Employed for Mid-Merit	N°	40	
Staff Employed for Peaking	N°	30	
Cost per person	£/yr	50000	
Total Cost for Baseload	£/yr	2250000	
Total Cost for Mid-Merit	£/yr	2000000	
Total Cost for Peaking	£/yr	1500000	

Dennenboslaan 26, 3090 Overijse, Belgium
Tel +32 477 544 095; Fax +32 2 772 50 44;
Email simon.minett@delta-ee.com; Web www.delta-ee.com

Sensitivity Case with GE H-class CCGT

REFERENCE POWER PLANT DATA

Reference Power Plant for Avoided Investment			
Combined Cycle Gas Turbine		GE H Class	
Size of Station	MW	400	
Primary Fuel		Natural Gas	
Secondary Fuel		Gas Oil	
Gas supply pressure		High Pressure	
Compression of Fuel		Yes	
Connection Voltage		200 kV	

Reference Power Plant Capital Investment			
CCGT Capital Cost	£/kWe	350	
CCGT Capital Cost	£ million	140	
Installation cost	£ million	14,0	10%
Grid Connection - shallow	£ million	5,0	
Total Costs	£ million	159,0	

Technical characteristics CCGT			
Design electrical efficiency LHV	%	60,00%	
Design electrical efficiency HHV	%	54,60%	
Design electrical output capacity	MW	400,0	
Thermal output capacity	MW	0,0	0%
Fuel Consumption at full load	MW	732,6	
Actual best electrical output at generator terminals	MW	388,0	53,0%
Inhouse loads	MW	9,5	2,4%
Degradation of CCGT over year	MW	7,8	2,0%
Net electrical output	MW	370,8	
Net electrical efficiency (HHV)	%	50,6%	
Annual electrical efficiency - baseload		50,6%	
Annual electrical efficiency - mid-merit		47,1%	93%
Annual electrical efficiency - peaking		44,5%	88%
Share of Primary Fuel	%	100%	
Primary Fuel Consumption	MW	732,6	
Share of Secondary Fuel	%	0%	
Secondary Fuel Consumption	MW	0,0	

Operational Data			
Variable operation and maintenance cost	p/kWh	0,3	
Fixed O&M	£/a	50000	

Labour used on CCGT power station			
Staff Employed for Baseload	N°	45	
Staff Employed for Mid-Merit	N°	40	
Staff Employed for Peaking	N°	30	
Cost per person	£/yr	50000	
Total Cost for Baseload	£/yr	2250000	
Total Cost for Mid-Merit	£/yr	2000000	
Total Cost for Peaking	£/yr	1500000	

Dennenboslaan 26, 3090 Overijse, Belgium
Tel +32 477 544 095; Fax +32 2 772 50 44;
Email simon.minett@delta-ee.com; Web www.delta-ee.com

Reference Boiler Plants Data

REFERENCE BOILER PLANT

SIZE CASE		1 kWe	1 MWe	10 MWe	50 MWe	350 MWe
Description of the Boiler Installation						
Type of Boiler		Condensing	Shell Boiler	Shell Boilers	Water Tube Boilers	Water Tube Boilers
Primary Fuel		Natural Gas	Natural Gas	Natural Gas	Natural Gas	Natural Gas
Secondary Fuel		None	None	Gas Oil	Gas Oil	Refinery Wastes
Technical characteristics of the Replacement Boiler Installation						
Thermal output capacity	Tonnes				85.0	500.0
Thermal output capacity of CHP plant	MW	0.0060	1.4	15.0	63.8	375.0
Thermal output capacity of Reference Boiler plant	MW	0.0260	2.0	20.0	75.0	540.0
Full Load Efficiency (LHV)	%	102.0%	92.0%	88.0%	86.0%	86.0%
Full Load Efficiency (HHV)	%	92.8%	83.7%	80.1%	78.3%	78.3%
Fuel Consumption per hour at full load	MW	0.0059	1.6	17.0	74.1	436.0
Share of Primary Fuel	%	100%	100%	98%	98%	75%
Primary Fuel Consumption	MW	0.0059	1.57	16.70	72.65	327.03
Share of Secondary Fuel	%	0%	0%	2%	2%	25%
Secondary Fuel Consumption	MW	0.0000	0	0.33	1.45	81.76
Reference Boiler Installation Costs						
Capital Costs	£/kW	35	80	60	70	65
Installation Costs	£/kW	50	25	25	25	20
Total Installation Cost	£	2210	210000	1700000	7125000	45900000
Fixed Maintenance Costs	£/a	150	1000	5000	20000	100000
Variable Maintenance Costs	p/kWh	0	0.1	0.05	0.05	0.05
Reference Boiler Operational Data						
Hours of operation	hrs	1800	5500	7000	8200	8300
Full Load Equivalent Hours	hrs	700	3950	5250	7000	5800
Heat Production	MWh	18.200	7900	105000	525000	3132000
Load factor of boilers	%	7.99%	45.09%	59.93%	79.91%	66.21%
Efficiency Loss due to Cycling	%	5.00%	5.00%	5.00%	5.00%	5.00%
Efficiency of boilers cycling	%	88.51%	80.22%	76.87%	75.20%	75.20%
Annual Consumption of Primary Fuel	MWh	20.562	9848	133856	684197	3123766
Annual Consumption of Secondary Fuel	MWh	0.000	0	2732	13963	1041255
Total Annual Fuel Consumption	MWh	20.562	9848	136588	698160	4165022

Grid Losses

Grid Losses			
Average Grid Losses Reported by DUKES	%	8,70%	2003 Data
Theoretical Calculations			
Transformation losses	%	0,8%	per transformation
Power Station to High Voltage Grid	N°	1	
High Voltage to Medium Voltage	N°	1	
Medium to Low Voltage	N°	1	
Low Voltage to Consumer	N°	1	
Heating losses HV	%	1,0%	
Heating losses MV	%	3,0%	
Heating losses LV	%	5,0%	
T&D Losses for HV connected customers	%	2,6%	
T&D Losses for MV connected customers	%	6,4%	
T&D Losses for LV connected customers	%	12,2%	

Carbon Emissions

CARBON DIOXIDE EMISSIONS

Fuel CO2			
Coal	kg/MWh	327,0	HHV
Oil Mix	kg/MWh	268,0	HHV
Gas Oil	kg/MWh	250,0	HHV
Natural Gas	kg/MWh	183,0	HHV
Refinery Off Gases	kg/MWh	150,7	HHV

Fuel Carbon			
Coal	kg/MWh	89,2	HHV
Oil Mix	kg/MWh	73,1	HHV
Gas Oil	kg/MWh	68,2	HHV
Natural Gas	kg/MWh	49,9	HHV
Refinery Off Gases	kg/MWh	41,1	HHV
Fossil Fuel Mix	kg/MWh	69,5	HHV

Note 1 — *CO2 to Carbon divide by* — *3,6667*

Note 2 — *Refinery Gases*

There is huge variation in the carbon content and calorific values of refinery off-gases - depending on the refinery input fuels and refinery products at any one time.

It is not right to assume that using refinery off-gases (or for that matter other waste fuels) is necessarily a zero carbon option.

Typically the carbon content of refinery off-gases is about 15% less than natural gas and the CV is about the same as natural gas. This would mean that the carbon content is 42.4 kg/MWh (compared to 49.9 for natural gas).

The amount of flaring on a refinery site depends highly on the refinery and the volume of throughput. Flaring is done when production exceeds any potential useful use (in boilers or other burners). With a large CHP plant then this out-of-balance is not going to occur. The share of flaring compared with other use could range between 1% and as much as 5%. A reasonable share, which could be viewed as typical of the UK, is 3% flaring.

Thus the net carbon content of refinery off-gases to be used in the model will be 41.1 kg/MWh.

Dennenboslaan 26, 3090 Overijse, Belgium
Tel +32 477 544 095; Fax +32 2 772 50 44;
Email simon.minett@delta-ee.com; Web www.delta-ee.com

ANNEX 3: DATA REFERENCE PLANTS (MOST LIKELY DISPLACEMENT APPROACH)

Power Generation Statistics			
Average Efficiency of CCGTs excluding own use	%	46,40%	2003 Data
Average Efficiency of Thermal Power Plants	%	38,80%	2003 Data
Share of Coal	%	49,56%	2003 Data
Efficiency of Coal Generation including own use	%	34,34%	2003 Data
Share of Gas	%	49,69%	2003 Data
Efficiency of Gas Generation including own use	%	44,98%	2003 Data
Share of Oil	%	0,76%	2003 Data
Efficiency of Oil Generation including own use	%	25,62%	2003 Data

Source DUKES 2004

DUKES 2004 ANALYSIS FOR DATA OF 2003

EFFICIENCY	Major Power Producers only	
Fuel Used	906712	GWh
Total Generation	362600	GWh
Own Use	16747	GWh
Pumped Storage	3546	GWh
Losses	29794	GWh
Final Supply	312513	GWh
Efficiency	34,47%	
Losses	8,70%	

EFFICIENCY OF POWER STATIONS					Conversion
CCGT	46,4%	HHV	50,99%	LHV	1,099
Coal	36,0%	HHV	37,50%	LHV	1,042
Oil					1,050

Plant Load Factors	
CCGT	59,8%
Other thermal	50,0%
Nuclear	76,3%

SHARES OF FUELS	Major Power Producers only					
	Coal	Oil	Gas	Nuclear	Bio-fuels	Totals
Fuel Used	371878	7604	284662	233080	4187	901411
Generation	134023	2197	131238	88686	1154	357298
Own Use	6325	249	3201	6775	95	16645
Supplied	127698	1948	128037	81911	1059	340653
With Nuclear and Biofuels						
Own Use Share	4,72%	11,33%	2,44%	7,64%	8,23%	
Gross Efficiency	34,34%	25,62%	44,98%	35,14%	25,29%	
Efficiency excl own use	36,04%	28,89%	46,10%	38,05%	27,56%	
Share of Thermal Generation	37,49%	0,57%	37,59%	24,05%	0,31%	
Coal, Oil and Gas Only						
Share of Thermal Generation	49,56%	0,76%	49,69%			
Average Efficiency						38,80%
Inhouse Use %	4,72%	11,33%	2,44%	7,64%		

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Email simon.minett@delta-ee.com; Web www.delta-ee.com

The Digest of UK Energy Statistics

The UK Department of Trade and Industry (DTI) produces a large number of energy statistics, amongst which is the annual Digest of UK Energy Statistics. DUKES also reports efficiencies of CCGT plants in the UK (www.dti.gov.uk/energy/inform/dukes/), which is based upon operational data from the UK power producers.

This paper uses the data from DUKES 2004, which is for power station performance in 2003. On 29 July 2005 the 2005 report was published. This new data has not yet been analysed.

Statistics on efficiency can be found in Table 5.10 of the report. The CCGT plants in operation in 2003 are found in Table 5.11. In total 33 CCGT sites are in the report with a total capacity of 23000 MW.

Figure 1 gives the increase of CCGT capacity in the UK over the years from 1991 to 2004. The CCGT capacity grew from 1800 MW in 1991 to 23000 MW in 2003. The UK has by far the largest and most modern state-of-the-art CCGT capacity, so it is a good source for reference efficiency values, and the official DUKES report fulfils the above mentioned criteria for defining the reference values.

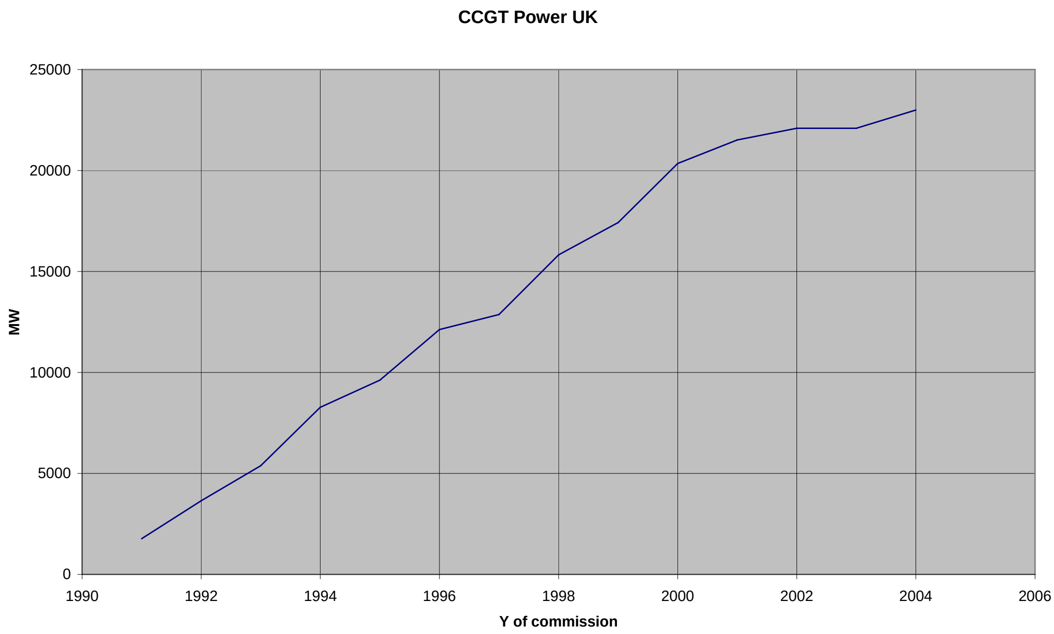

Figure 1: CCGT capacity in the UK in 2003 (source DUKES 2003)

In conclusion, from the three sources discussed before the DUKES reporting on CCGT efficiencies is the only one that reports real operational data and fulfils the criteria of the Directive. Therefore it is proposed to use these data as input for the reference efficiency values for electricity production of gas fired CHP.

DUKES report on CCGT operation efficiency

The CCGT efficiencies can be found in Table 5.10 of the report. These figures are gross efficiencies on gross calorific basis. The reporting period is from 1996 to 2003.

Figure 2 gives the reported efficiency of the UK CCGT plants as net efficiencies based on lower heating value. They have been corrected as follows:

- LHV = 0.9 * GCV

Dennenboslaan 26, 3090 Overijse, Belgium
Tel +32 477 544 095; Fax +32 2 772 50 44;
Email simon.minett@delta-ee.com; Web www.delta-ee.com

- net efficiency = 0.975 * gross efficiency (note this is also based on data reported in DUKES)

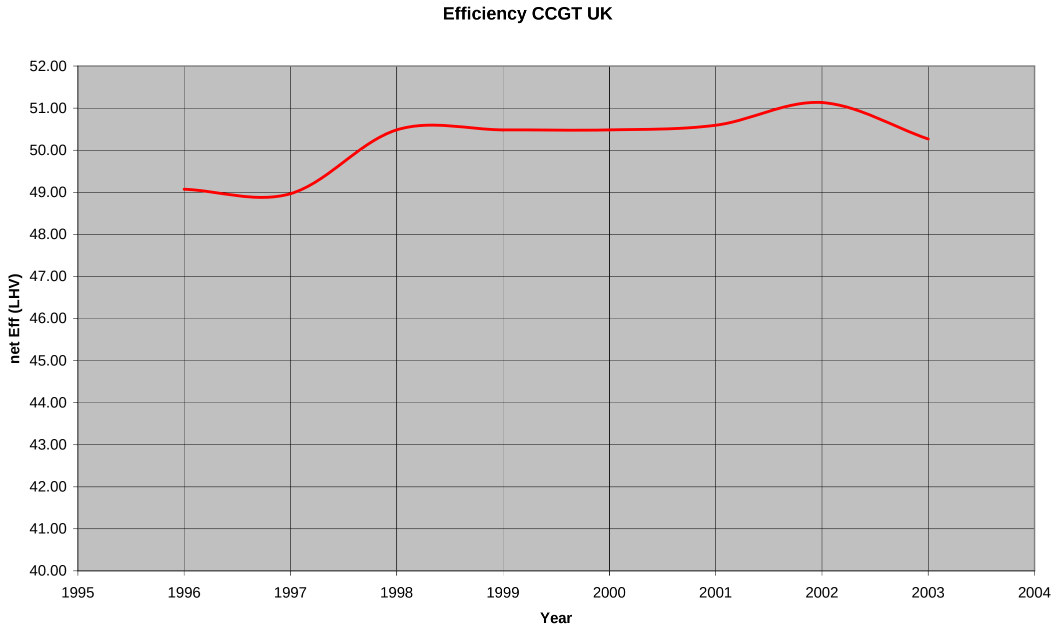

Figure 2: net CCGT efficiency (source DUKES 2003)

From these data it can be concluded that the huge increase of CCGT capacity with new state-of-the-art CCGT units has resulted in only a slight increase of CCGT operational efficiency from 48.5% in 1996 to 50% in 2003.

The effect of older less efficient CCGTs on the reported average annual efficiency is small, because the older capacity is small compared to the newly installed capacity, and due to market forces the production of the older units will have decreased in favour of the new units.

Table 5.10 also shows that after 2000 the CCGT plant load factor has decreased. This is an illustration of the more cycling operation of CCGT plants, because of market conditions, instead of baseload operation in the past.

REFERENCE BOILER PLANT

SIZE CASE		1 kWe	1 MWe	10 MWe	50 MWe	350 MWe
Old Boiler Operational Data						
Age of Boilers	Yr	15	20	30	30	35
Fuel Used		Same	Same	Same	Same	Same
Heat Output	MWh	18.200	7900	105000	525000	3132000
Boiler Plant Efficiency	%	60.00%	75.00%	73.00%	73.00%	73.00%
Annual Consumption of Primary Fuel	MWh	30.333	10533	140959	704795	3217808
Annual Consumption of Secondary Fuel	MWh	0.000	0	2877	14384	1072603
Total Annual Fuel Consumption	MWh	30.333	10533	143836	719178	4290411

Dennenboslaan 26, 3090 Overijse, Belgium
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Email simon.minett@delta-ee.com; Web www.delta-ee.com