Combined Heat and Power Carbon Savings

What is the potential CO_2 saving from installing CHP?

Will feed-in tariffs unlock this potential?

James Thonger

What is Combined Heat and Power ?

The CHP process involves the conversion of high grade heat to mechanical power using a heat engine.

- The conversion of this mechanical power to electrical power.
- The use of lower grade (waste) heat for heating.

The efficiencies of all these processes are interactive.

The efficiency of the heat engine has a maximum theoretical efficiency (2nd Law of Thermodynamics) called the Carnot efficiency. .... this is defined as follows:-

$$\text{Carnot Efficiency} = \frac{\text{(Hot temperature – Cold temperature)}}{\text{Hot Temperature}}$$

(all temperatures are absolute)

So ...... if the heat network requires good quality heat the efficiency of electrical conversion is affected ...... as follows :-

---

Power only Heat Engine - Fuel burn temperature say 570 Deg C

Coolant temperature say 40 Deg C

Carnot Efficiency = (570 – 40) / (570 + 273)

= 63 %

CHP Heat Engine - Fuel burn temperature say 570 deg C

Coolant temperature say 90 Deg C

Carnot Efficiency = (570 – 90) / (570 + 273)

= 57 %

The efficiency difference is a reduction of (63 – 57) / 62 = 10 %

This is the reason why CHP is not similar to a car heater.

How do we calculate the CO_2 savings by using CHP

We first need to decide what we are comparing with :-

Before 2007, CHP was compared against an electrical Grid mix that included a significant proportion of Coal Fired electricity.

Since November 2007, CHP is compared against a same fuel source as required by the European Directive for Co-Generation.

To calculate Energy Savings we now use the method specified in DEFRA's CHPQA and the EU Directive on Co-Generation. 2004/8/EC

EN Official Journal of the European Union

DIRECTIVE 2004/8/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

of 11 February 2004

on the promotion of cogeneration based on a useful heat demand in the internal energy market and amending Directive 92/42/EEC

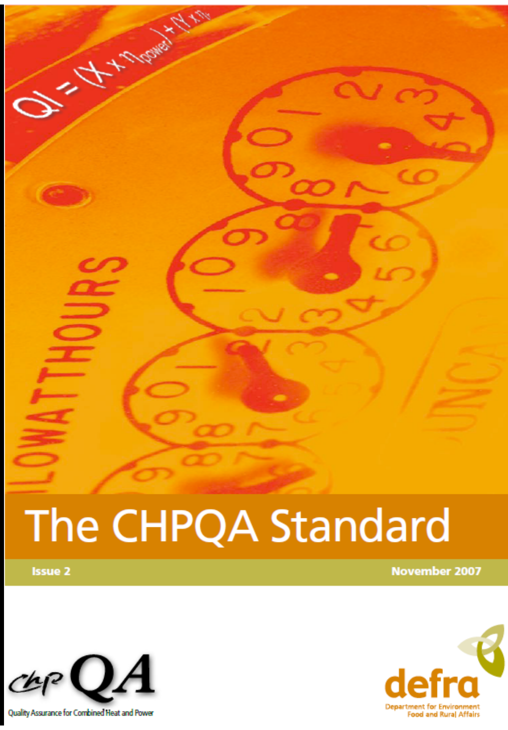
(f) *Efficiency reference values for separate production of heat and electricity*

The principles for defining the efficiency reference values for separate production of heat and electricity referred to in Article 4(1) and in the formula set out in paragraph (b) of this Annex shall establish the operating efficiency of the separate heat and electricity production that cogeneration is intended to substitute.

The efficiency reference values shall be calculated according to the following principles:

1. For cogeneration units as defined in Article 3, the comparison with separate electricity production shall be based on the principle that the same fuel categories are compared.

CHPQA



EU Directive and CHPQA states that :-

Co-Generation can only claim to save Energy if it is more efficient than conventional energy supply …… using the same fuel source.

Carbon Dioxide saving cannot be claimed if the Co-Generation system is less efficient than conventional energy supply …… using the same fuel source.

(b) *Calculation of primary energy savings*

The amount of primary energy savings provided by cogeneration production defined in accordance with Annex II shall be calculated on the basis of the following formula:

$$PES = \left(1 - \frac{1}{\frac{CHP\,H\eta}{Ref\,H\eta} + \frac{CHP\,E\eta}{Ref\,E\eta}} \right) \times 100\,\%$$

Where:

PES is primary energy savings.

CHP Hη is the heat efficiency of the cogeneration production defined as annual useful heat output divided by the fuel input used to produce the sum of useful heat output and electricity from cogeneration.

Ref Hη is the efficiency reference value for separate heat production.

CHP Eη is the electrical efficiency of the cogeneration production defined as annual electricity from cogeneration divided by the fuel input used to produce the sum of useful heat output and electricity from cogeneration. Where a cogeneration unit generates mechanical energy, the annual electricity from cogeneration may be increased by an additional element representing the amount of electricity which is equivalent to that of mechanical energy. This additional element will not create a right to issue guarantees of origin in accordance with Article 5.

Ref Eη is the efficiency reference value for separate electricity production.

Example:

CHP Reference Values for Natural Gas

Heating Energy - Currently the accepted reference heat source is a modern gas fired condensing boiler with an average thermal efficiency of 90% (NCV). (SEDBUK A) This is equivalent to 81% GCV.

Electrical Energy – as delivered by the Grid using CCGT Which has an efficiency of 47% GCV for installations exceeding 50 kV.

Typical Gas Fired Combined Heat and Power (CHP) using Gross Calorific Value of Natural Gas

30%

40%

0.40 kW.hr
HEAT

GAS 1 kW.hr @ 0.184 $kgCO_2/kW.hr$

0.30 kW.hr
ELEC

30%

TOTAL CARBON DIOXIDE EMISSION = 0.184 $Kg.CO_2$

Conventional Gas Fired Heating + Electric using CHPQA electrical supply reference factor

19%

81%

GAS 0.49 kW.hr @ 0.184 $kgCO_2$/kW.hr — 0.40 kW.hr HEAT

ELEC 0.30 kW.hr @ 0.391 $kgCO_2$/kW.hr — 0.30 kW.hr ELEC

Carbon Dioxide Emission From Gas = 0.49 x 0.184 = 0.092 kg.CO_2

Carbon Dioxide Emission From Elec = 0.30 x 0.391 = 0.117 kg.CO_2

TOTAL CARBON DIOXIDE EMISSION (conventional) = 0.209 Kg.CO_2

TOTAL CARBON DIOXIDE EMISSION (CHP) = 0.184 Kg.CO_2

Primary Energy Saving calculated using the European Directive

	Electrical	Heat	Total CO_2
CHP	**30 kW.hr**	**40 kW.hr**	**18.4 kg**
Conventional			**20.9 kg**

Primary Energy Saving using CHP = (20.9 – 18.4) / 20.9 = 12 %

CHP connected to a heat network with pumps and 10% heat loss

	Electrical	Heat	Total CO_2
CHP	**27 kW.hr**	**36 kW.hr**	**18.4 kg**
Conventional			**18.7 kg**

PES using CHP with heat network = (18.7– 18.2) / 18.7 = 3 %

(b) *Calculation of primary energy savings*

The amount of primary energy savings provided by cogeneration production defined in accordance with Annex II shall be calculated on the basis of the following formula:

$$PES = \left(1 - \frac{1}{\frac{CHP\ H\eta}{Ref\ H\eta} + \frac{CHP\ E\eta}{Ref\ E\eta}} \right) \times 100\ \%$$

Where:

PES is primary energy savings.

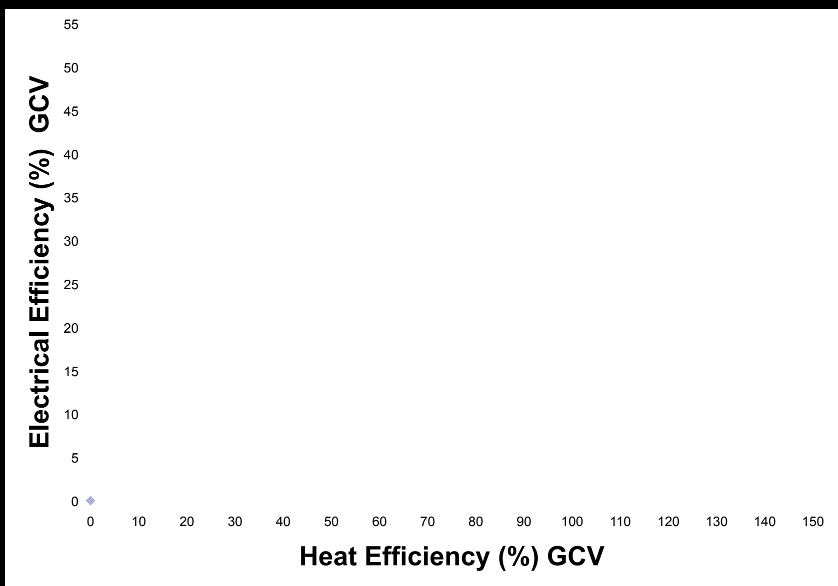
CHP Hη is the heat efficiency of the cogeneration production defined as annual useful heat output divided by the fuel input used to produce the sum of useful heat output and electricity from cogeneration.

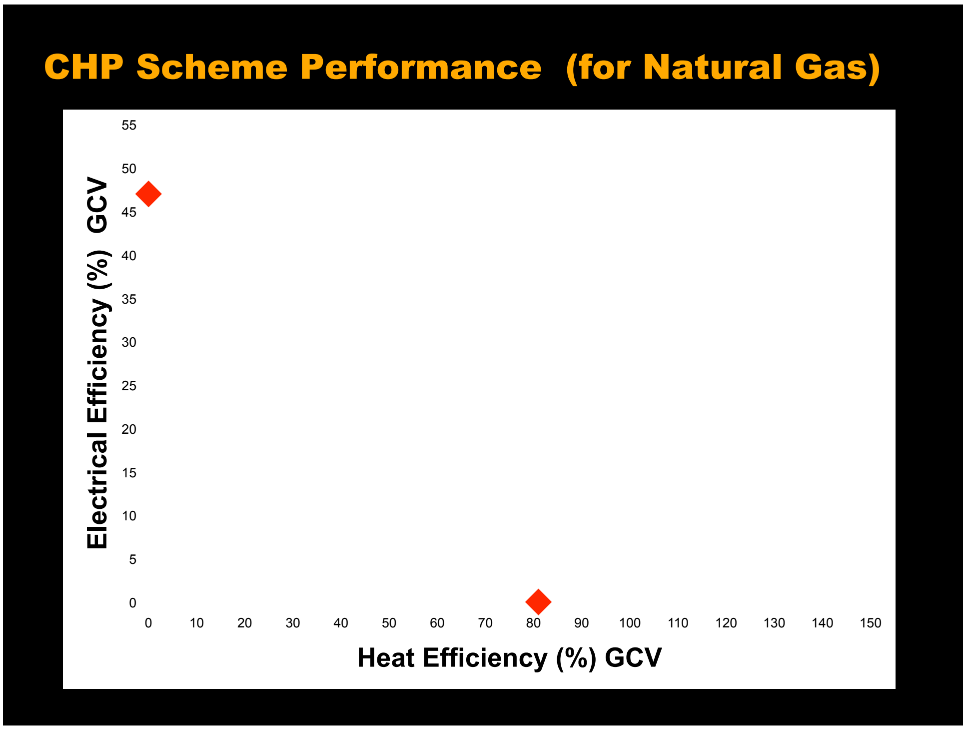
Ref Hη is the efficiency reference value for separate heat production.

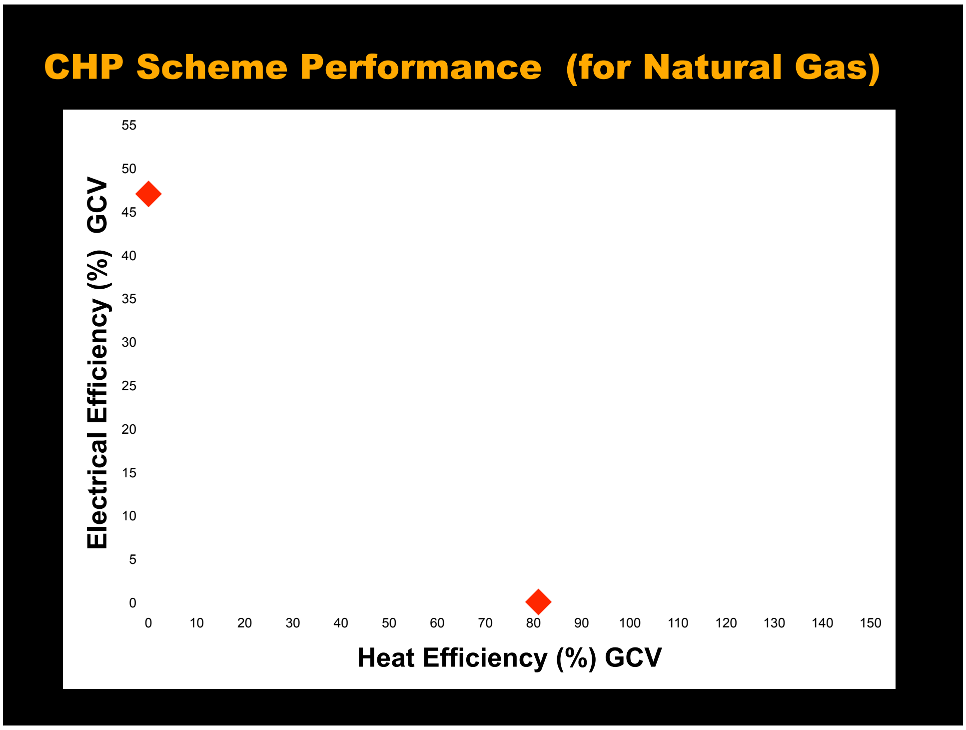
CHP Eη is the electrical efficiency of the cogeneration production defined as annual electricity from cogeneration divided by the fuel input used to produce the sum of useful heat output and electricity from cogeneration. Where a cogeneration unit generates mechanical energy, the annual electricity from cogeneration may be increased by an additional element representing the amount of electricity which is equivalent to that of mechanical energy. This additional element will not create a right to issue guarantees of origin in accordance with Article 5.

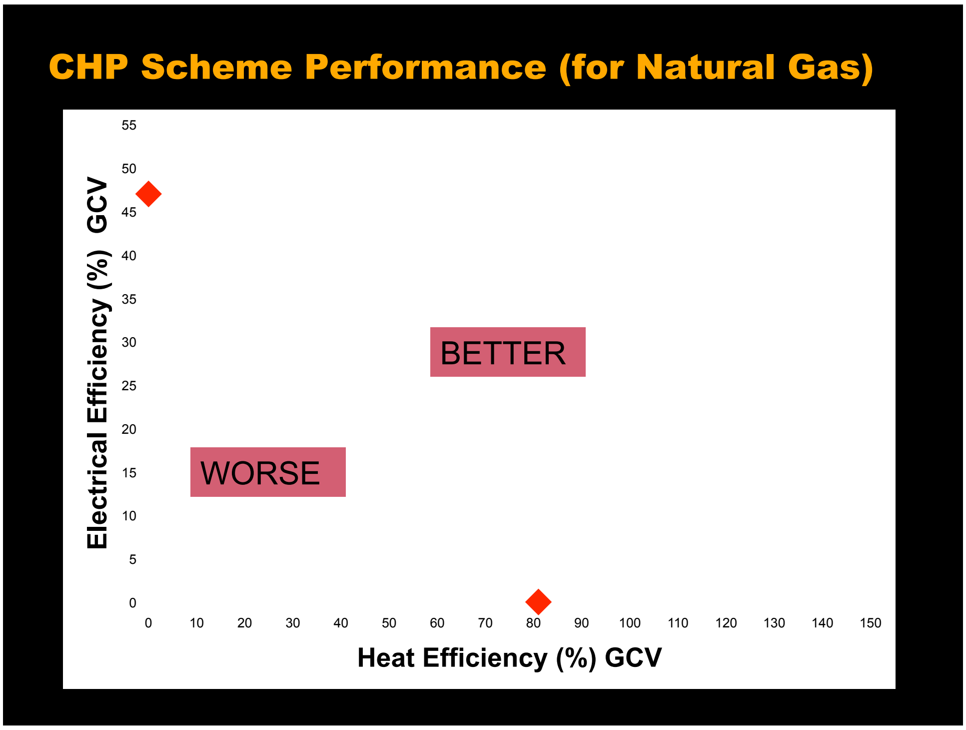
Ref Eη is the efficiency reference value for separate electricity production.

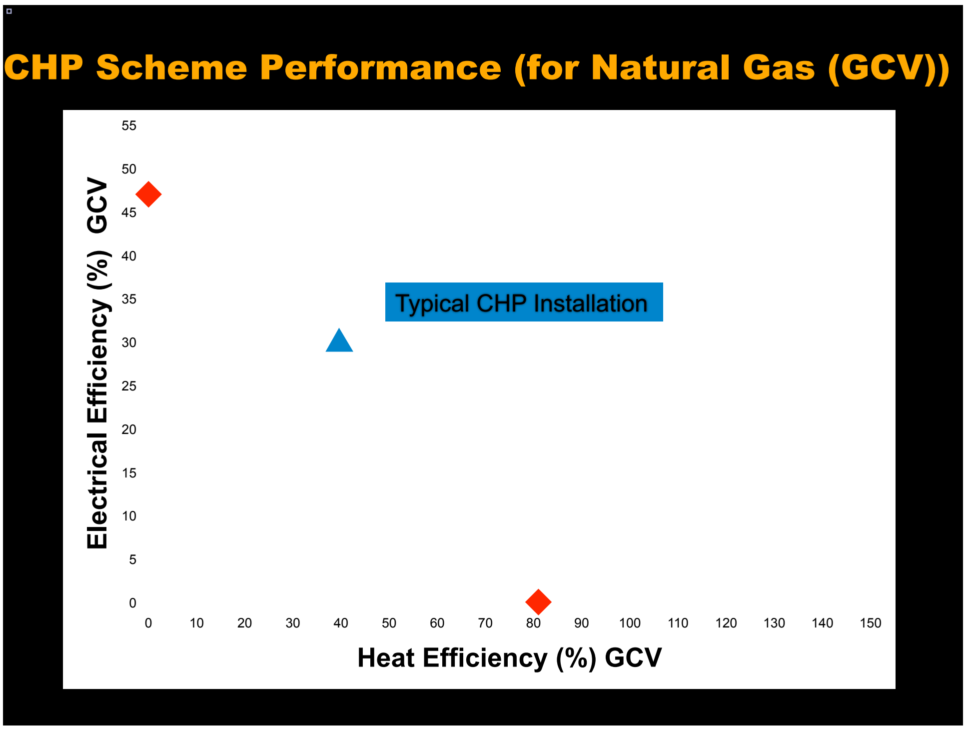
CHP Scheme Performance (for Natural Gas)



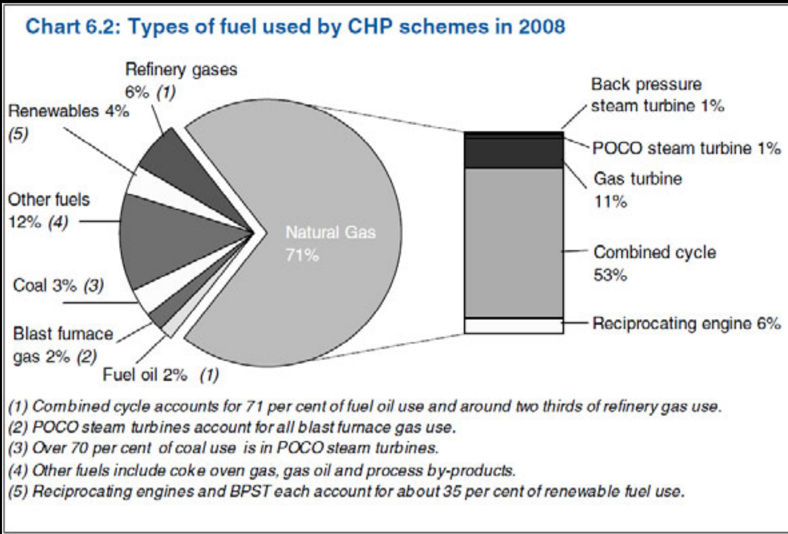

CHP Scheme Performance (for Natural Gas)
Electrical Efficiency (%) GCV
Heat Efficiency (%) GCV
0
5
10
15
20
25
30
35
40
45
50
55
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150


CHP Scheme Performance (for Natural Gas)
Electrical Efficiency (%) GCV
Heat Efficiency (%) GCV
0
5
10
15
20
25
30
35
40
45
50
55
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150


CHP Scheme Performance (for Natural Gas)
Electrical Efficiency (%) GCV
55
50
45
40
35
30
25
20
15
10
5
0
BETTER
WORSE
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150
Heat Efficiency (%) GCV


CHP Scheme Performance (for Natural Gas (GCV))
Electrical Efficiency (%) GCV
55
50
45
40
35
30
25
20
15
10
5
0
Typical CHP Installation
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150
Heat Efficiency (%) GCV

So..........how do existing (2008) 'Good Quality' CHP installations rate when compared to the EU Directive / CHPQA ?



from DUKES 2009

Table 6D: A summary of scheme performance in 2008

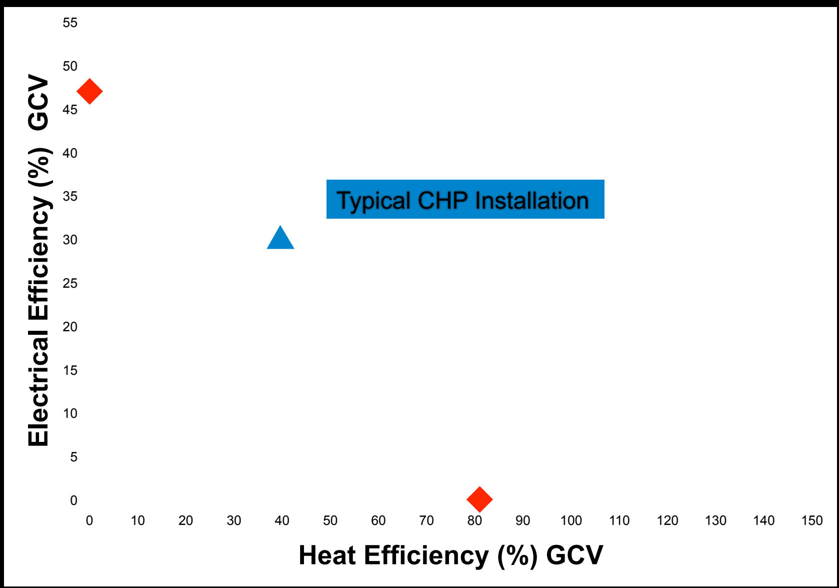
	Average operating hours per annum (Full load equivalent)	Average electrical efficiency (% GCV)	Average heat efficiency (% GCV)
Main prime mover in CHP plant			
Back pressure steam turbine	4,945	12	63
Pass out condensing steam turbine	3,905	14	44
Gas turbine	5,253	21	49
Combined cycle	5,510	26	41
Reciprocating engine	3,345	26	42
All schemes	**5,104**	**23**	**44**

from DUKES 2009

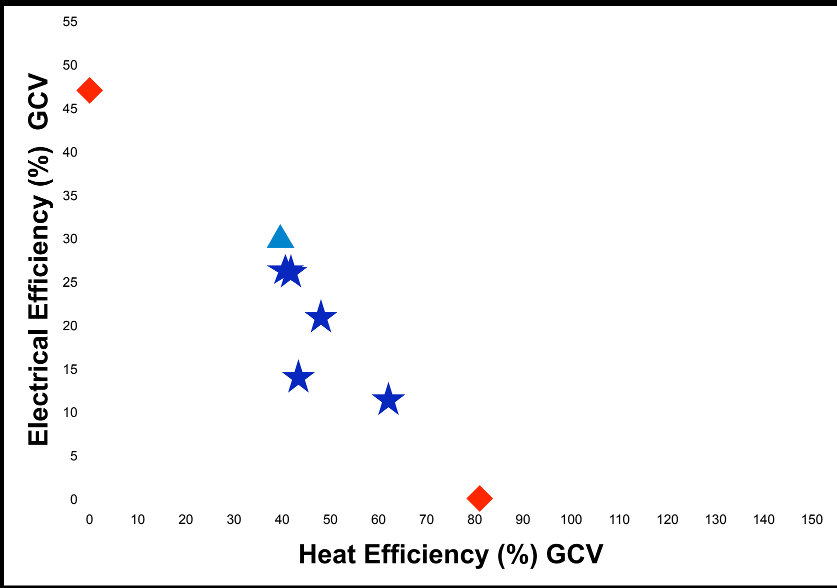
Primary Energy Savings in 2008 for UK Good Quality Gas fired CHP systems calculated using EU Directive reference factors

	Electrical Eff:ncy %	Heat Eff:ncy %	Overall Eff:ncy %	Primary Energy Savings
Back pressure steam turbine	12	63	75	3 %
Condensing steam turbine	14	44	58	- 19 %
Gas Turbine	21	49	70	5 %
CCGT	26	41	67	6 %
Reciprocating Engine	26	42	68	7 %
ALL Schemes	23	44	67	3 %

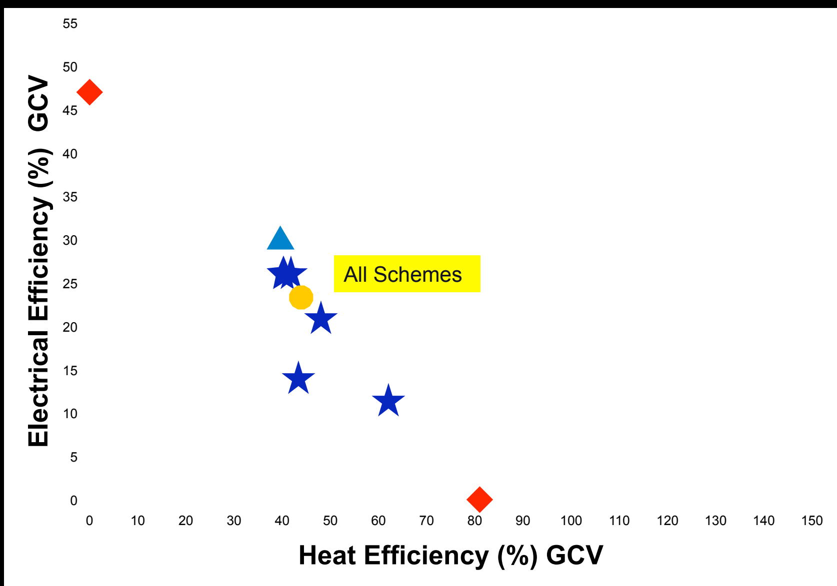
CHP Scheme Performance (for Natural Gas (GCV))



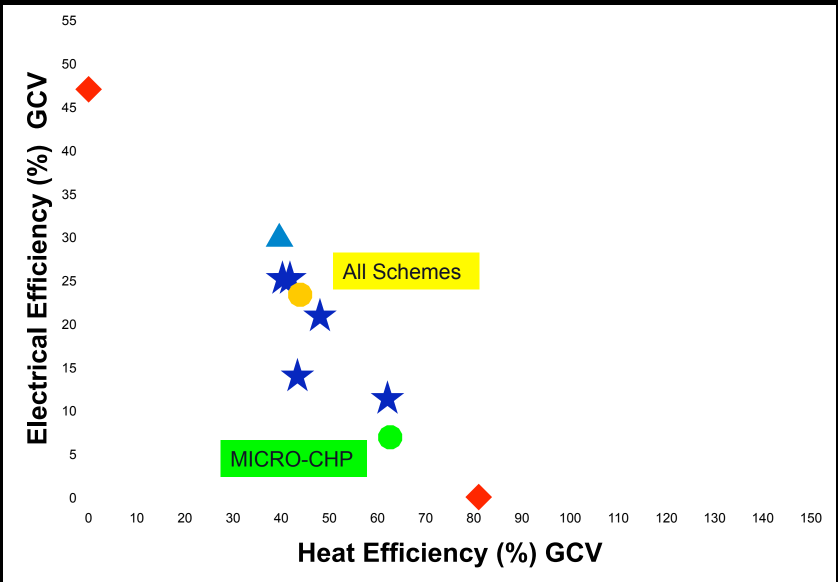
CHP Scheme Performance from DUKES 2009



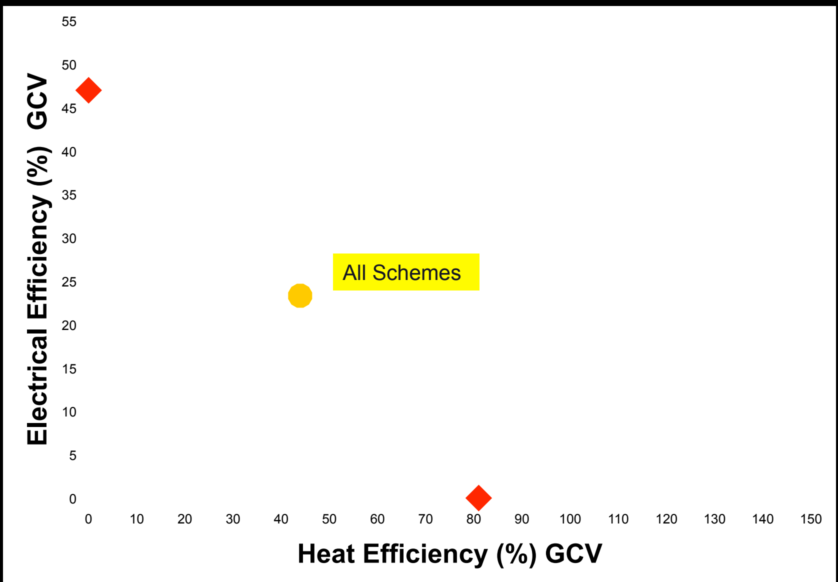
CHP Scheme Performance



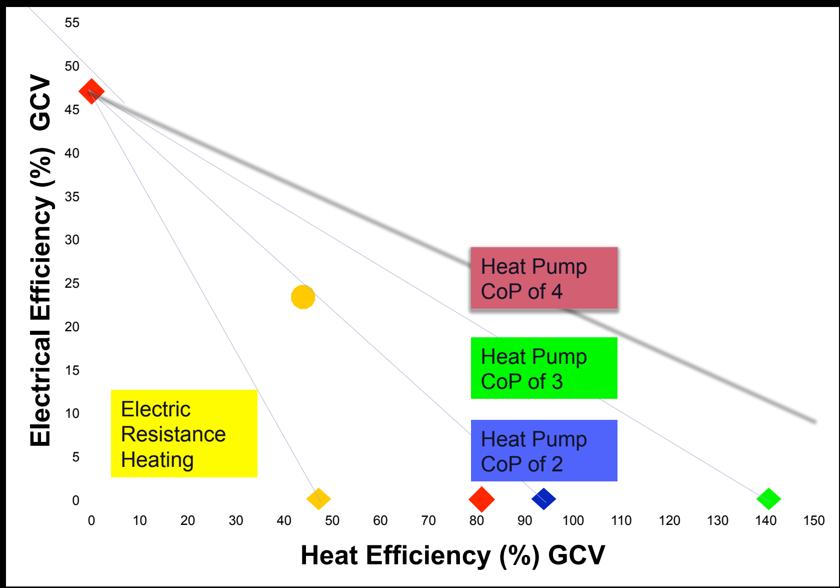
CHP Scheme Performance



CHP Scheme Performance



CHP Scheme Performance vs Electric Heating



To put this another way…

Taking the average Gas Fired CHP in the UK for 2008, the overall achieved efficiencies (from DUKES) were …

- Electrical 23%
- Heat 44%

If we assume that the CHP input gas load is 100%, then to provide the same amount of heating and power by conventional sources we would require…. ((23 / 47) + (44 / 81)) = 103% of the gas.

If we use conventional electrical supply and a heat pump with a CoP of 3 then we would require ……… (23 + (44 / 3)) / 47 = 80% of the fuel required for the CHP. In other words, in this example, the heat pump with electricity supplied by a CCGT on the Grid uses 20% less fuel than the CHP system to provide the same amount of heat and power.

THE FUTURE - my Prediction

- On route to 2050 - 80% Carbon Reductions for the whole UK
- The Electricity Grid will need to be decarbonised
- The Grid will supply more power for transport load
- Significant investment required in a Smart Grid
- Heating requirements will reduce
- Burning of Fossil Fuels in domestic properties will be illegal.
- Burning of any fossil fuel will be regulated
- Fossil Fuel burnt for any power generation (including CHP) will require Carbon Sequestration

What is the future for CHP and Heat Networks

- In the very short term modest Carbon savings can be realised using CHP provided it is Heat lead.
- Heat Pumps already offer better efficiency savings and Carbon Savings than CHP.
- Heat networks should only be proposed if the heat source is (or can be converted to) low grade renewable (or waste incineration).
- Any long term fossil fuel CHP installation must be capable of Carbon Sequestration.

Combined Heat and Power Carbon Savings

What is the potential CO_2 saving from installing CHP?

Modest – (in the short term only)

Will feed-in tariffs unlock this potential?

Feed-in tariffs should only be used to promote long term fuel efficiency and CO_2 reduction leading to the target 80% reduction.

We are in a period on unprecedented change. Fiscal policies should only be used to stimulate the introduction of technologies that achieve the long term objectives.

James Thonger