

# Tri Generation

Can it ever live up to the hype?

James Thonger

## Trigeneration – what is it.

Trigeneration is Co-Generation of the following :-

- **Electrical Power**
- **Useful Heat**
- **Useful Cooling**

It is promoted as a method of providing energy savings against conventional energy supply by using decentralised energy systems.

In calculation terms, **Energy Savings** are analysed by comparison with two separate processes :-

- Combined Heat and Power - CHP
- Combined Cooling and Power - CCP

# 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

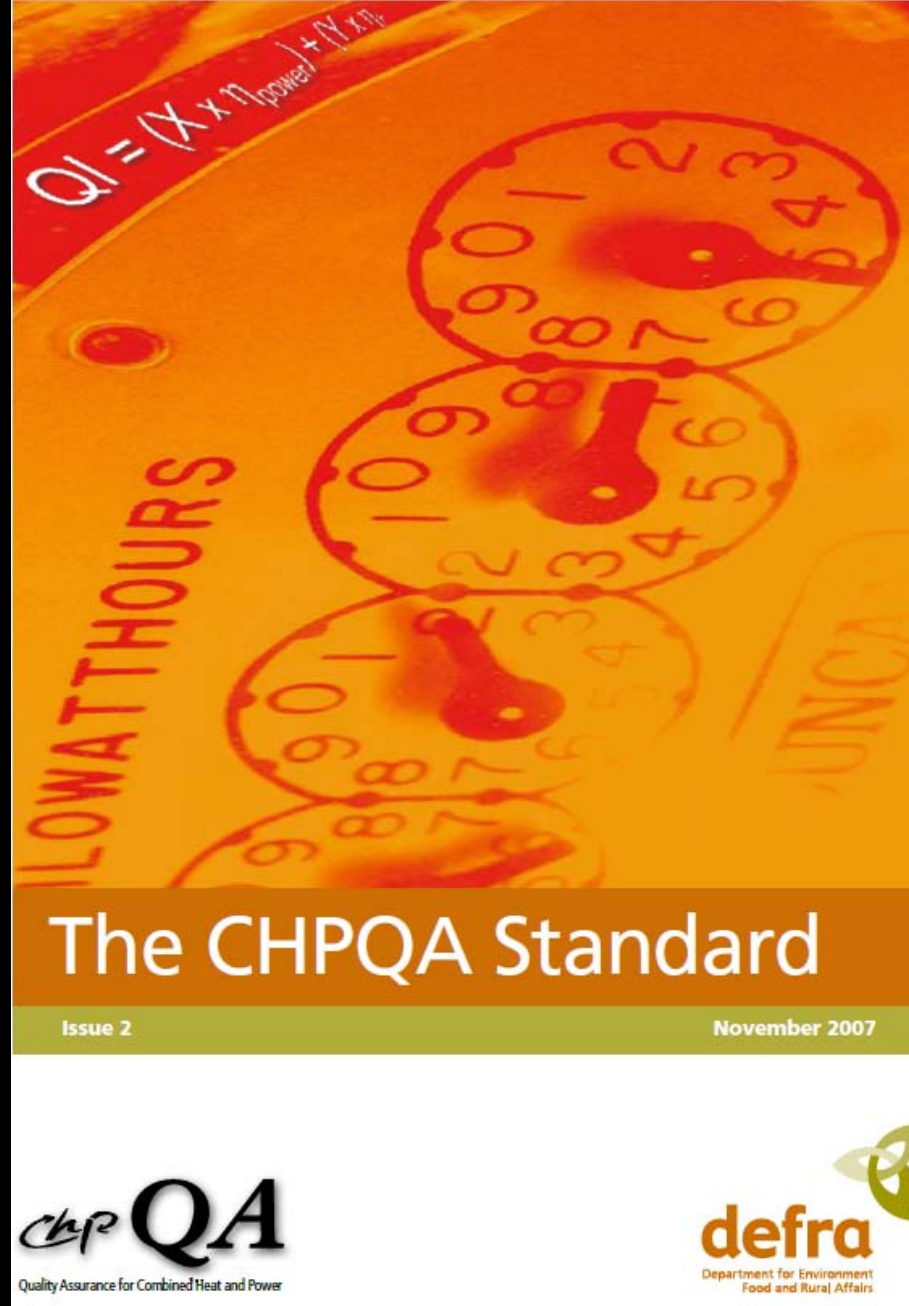
### (f) *Efficiency reference values for separate production of heat and electricity*

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

**Surprisingly, this is a concept that some notable organisations in the UK have difficulty understanding.**

(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:

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

Where:

PES is primary energy savings.

CHP H $\eta$  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 H $\eta$  is the efficiency reference value for separate heat production.

CHP E $\eta$  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 E $\eta$  is the efficiency reference value for separate electricity production.

# Tri Generation

For most of this discussion I will be concentrating on Tri-Generation using **Natural Gas** as the fuel source.

# CHP Reference Values

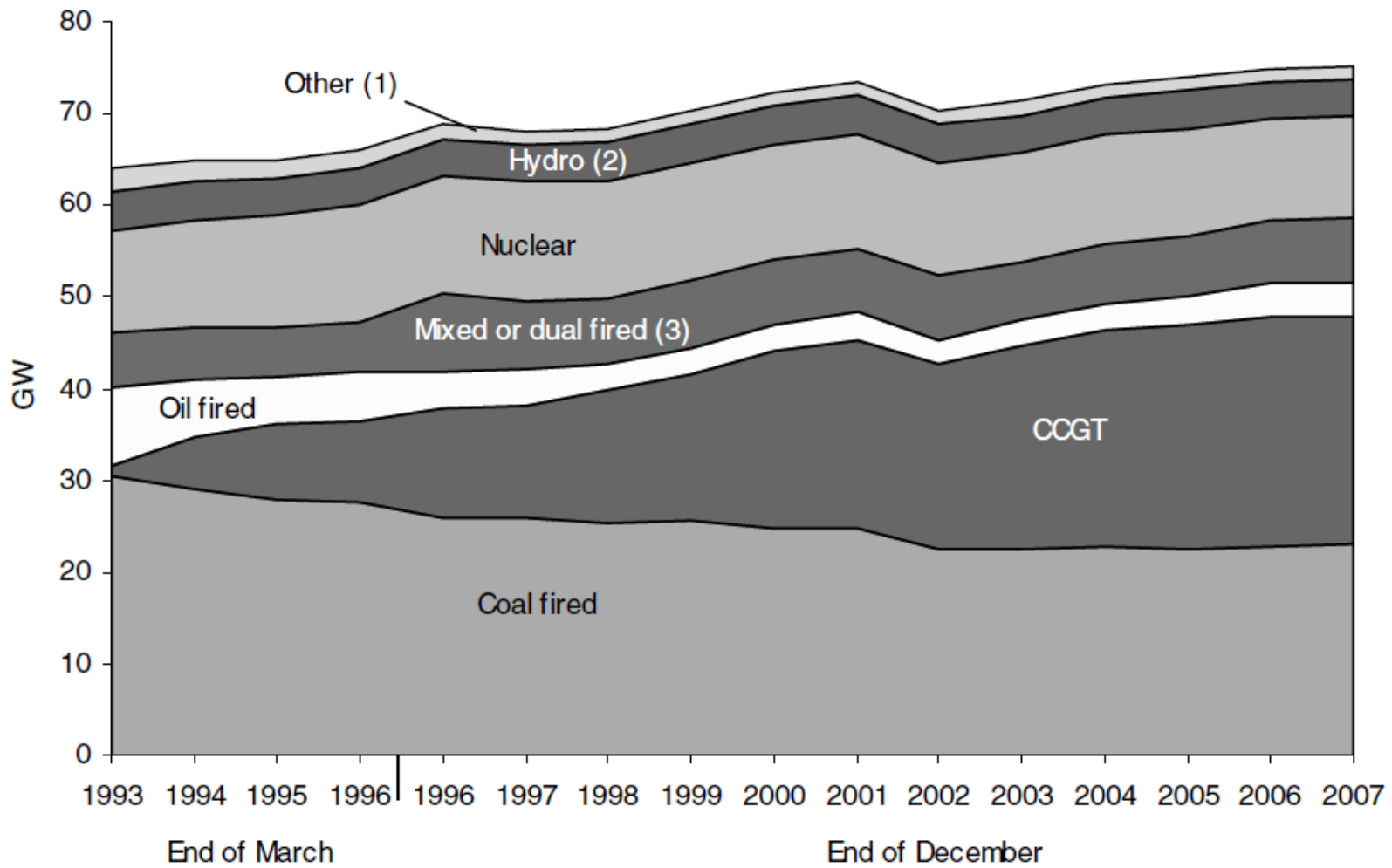
In order to calculate Primary Energy Savings (PES) we need to know the Reference Values for providing these energies from conventional sources **using the same fuel type.**

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

**Electrical Energy** – as delivered by the Grid using CCGT

# Electrical Grid Fuel Mix and Carbon Factors

Chart 5.4: Generating capacity of major power producers 1993-2007



From DUKES 2008

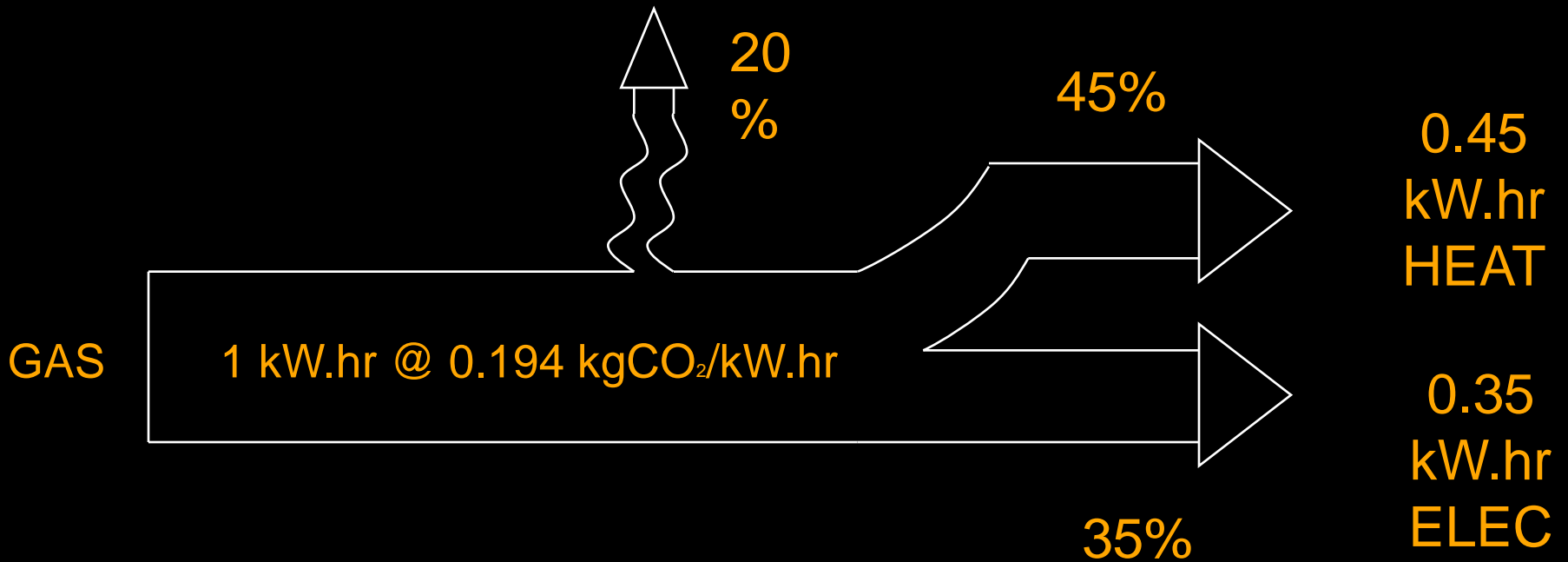
# Grid Supplied Electricity Carbon Intensities

(all electrical reference factors are given in kgCO<sub>2</sub>/kW.hr)

DTI / BERR Part L Building Regs Grid Supplied	=	0.422	
DTI / BERR Part L Building Regs Grid Displaced	=	0.568	- 35% higher
DEFRA average Grid Supplied & Displaced	=	0.430	- Current average
DUKES measured Average (all fuels) 2007	=	0.501	
DUKES Coal Average 2007	=	0.939	- Highest
DUKES Gas Average 2007	=	0.405	
EU Harmonised Reference Value (Gas)	=	0.396	
CHPQA (Gas Average)	=	0.396	- Lowest (for gas)

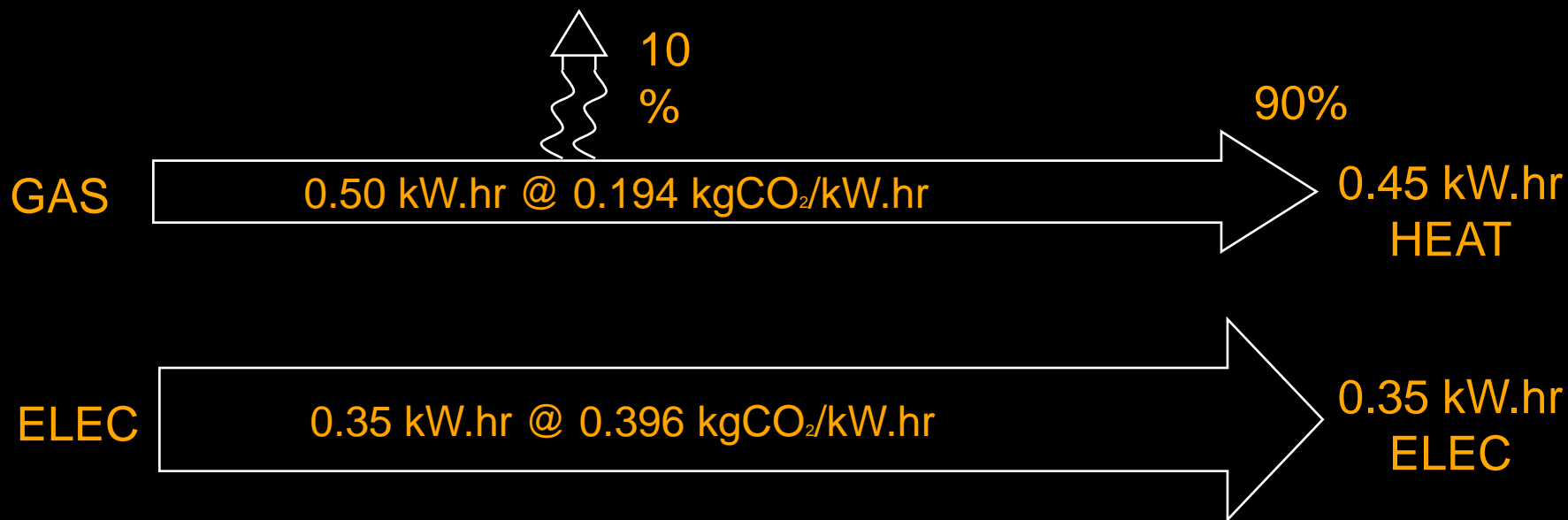
Highest is 2.4 times higher than the Lowest

# Typical Gas Fired Combined Heat and Power (CHP)



TOTAL CARBON DIOXIDE EMISSIONS = 1 x 0.194 = 0.194 Kg.CO<sub>2</sub>

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



Carbon Dioxide Emission From Gas =  $0.50 \times 0.194$  = 0.097 kg.CO<sub>2</sub>

Carbon Dioxide Emission From Electric =  $0.35 \times 0.396$  = 0.139 kg.CO<sub>2</sub>

TOTAL CARBON DIOXIDE EMISSION (conventional) = 0.236 Kg.CO<sub>2</sub>

TOTAL CARBON DIOXIDE EMISSION (CHP) = 0.194 Kg.CO<sub>2</sub>

Primary Energy Saving calculation using the CHPQA

	Electrical	Heat	Total CO <sub>2</sub>
CHP	35 kW.hr	45 kW.hr	194 kg
Conventional			236 kg

Primary Energy Saving using CHP =  $(236 - 194) / 236 = 18 \%$

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

	Electrical	Heat	Total CO <sub>2</sub>
CHP	32 kW.hr	40 kW.hr	194 kg
Conventional			213 kg

PES using CHP with heat network =  $(213 - 194) / 213 = 9 \%$

(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:

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

Where:

PES is primary energy savings.

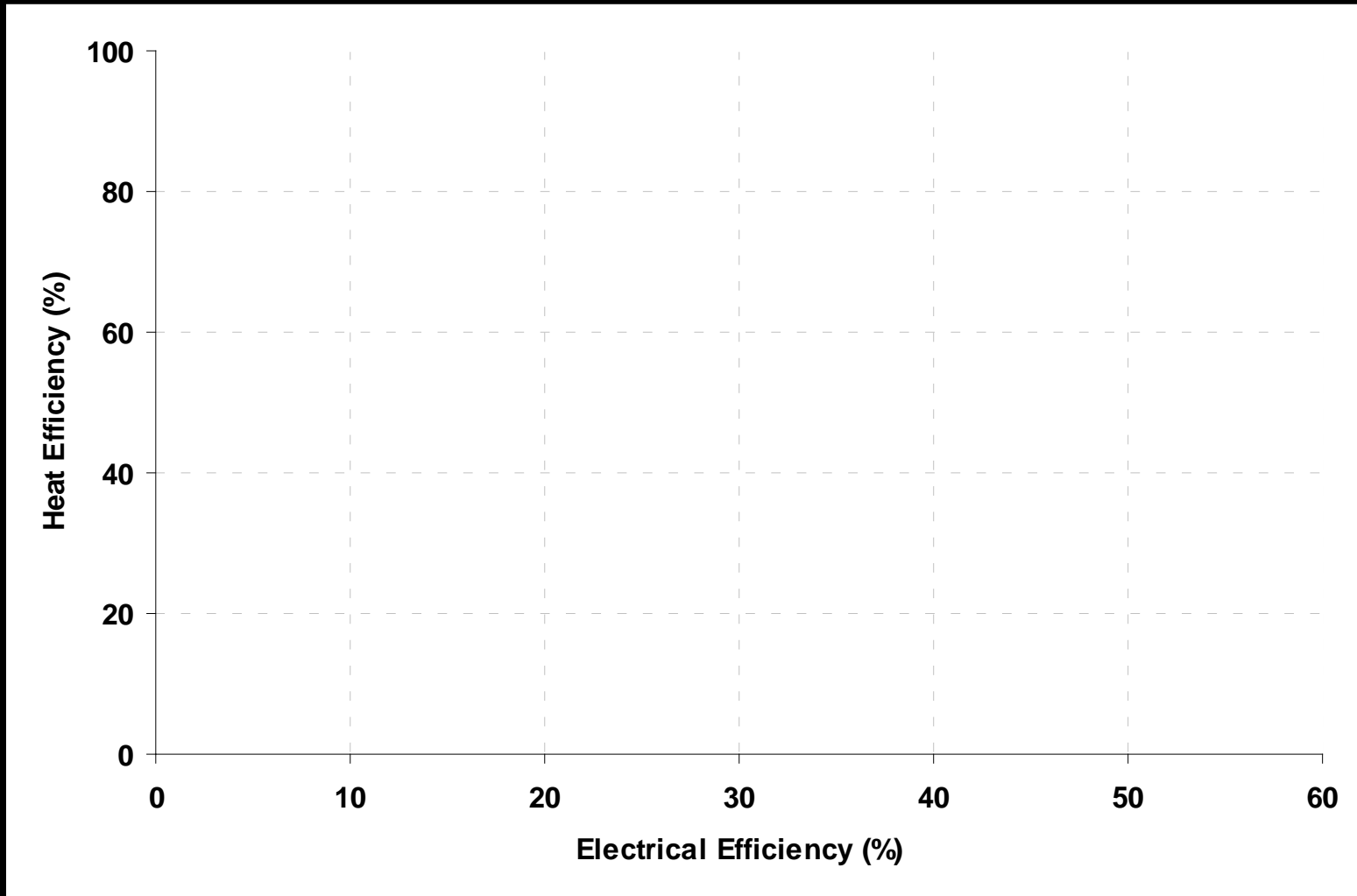
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Ref H $\eta$  is the efficiency reference value for separate heat production.

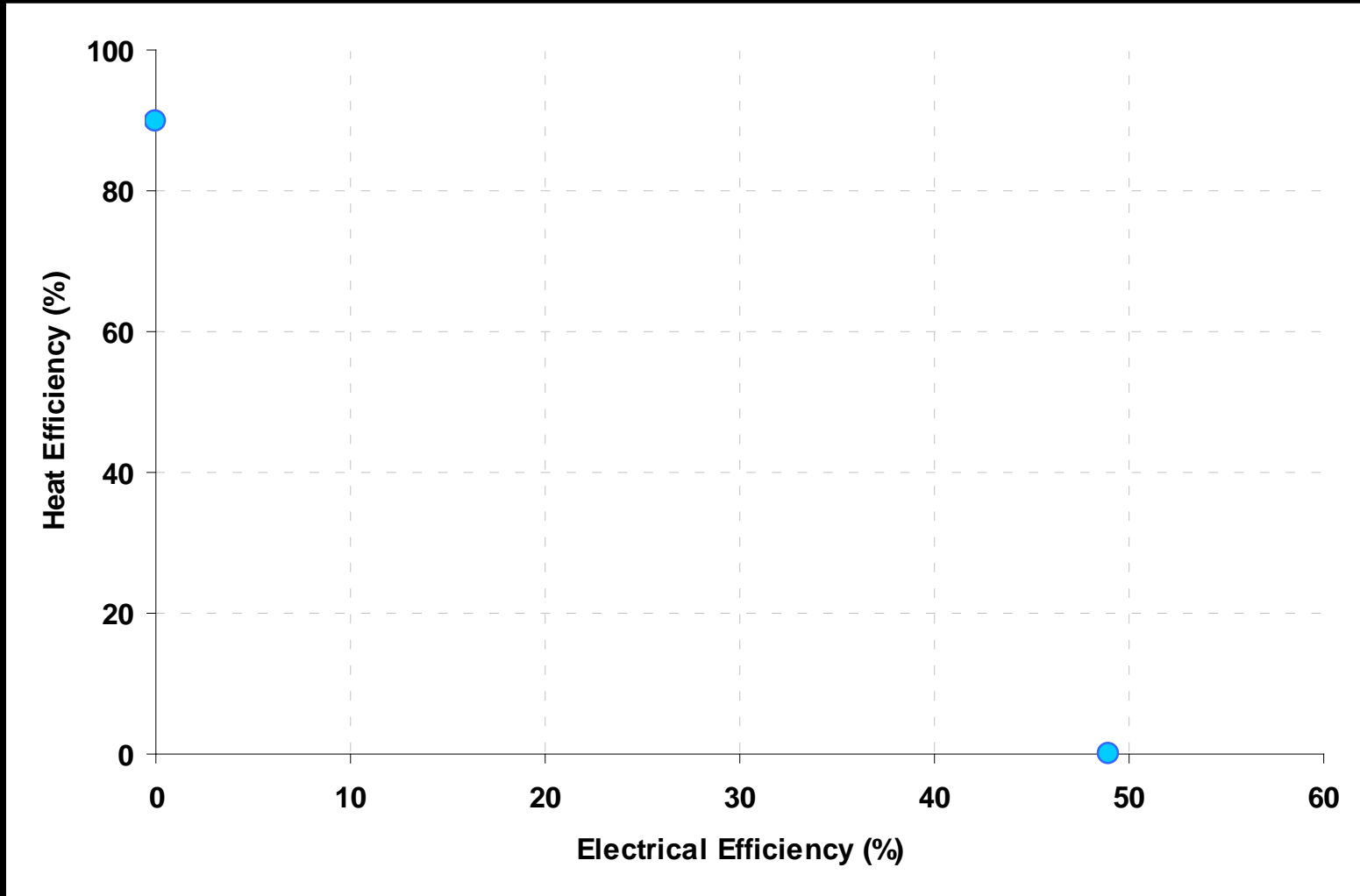
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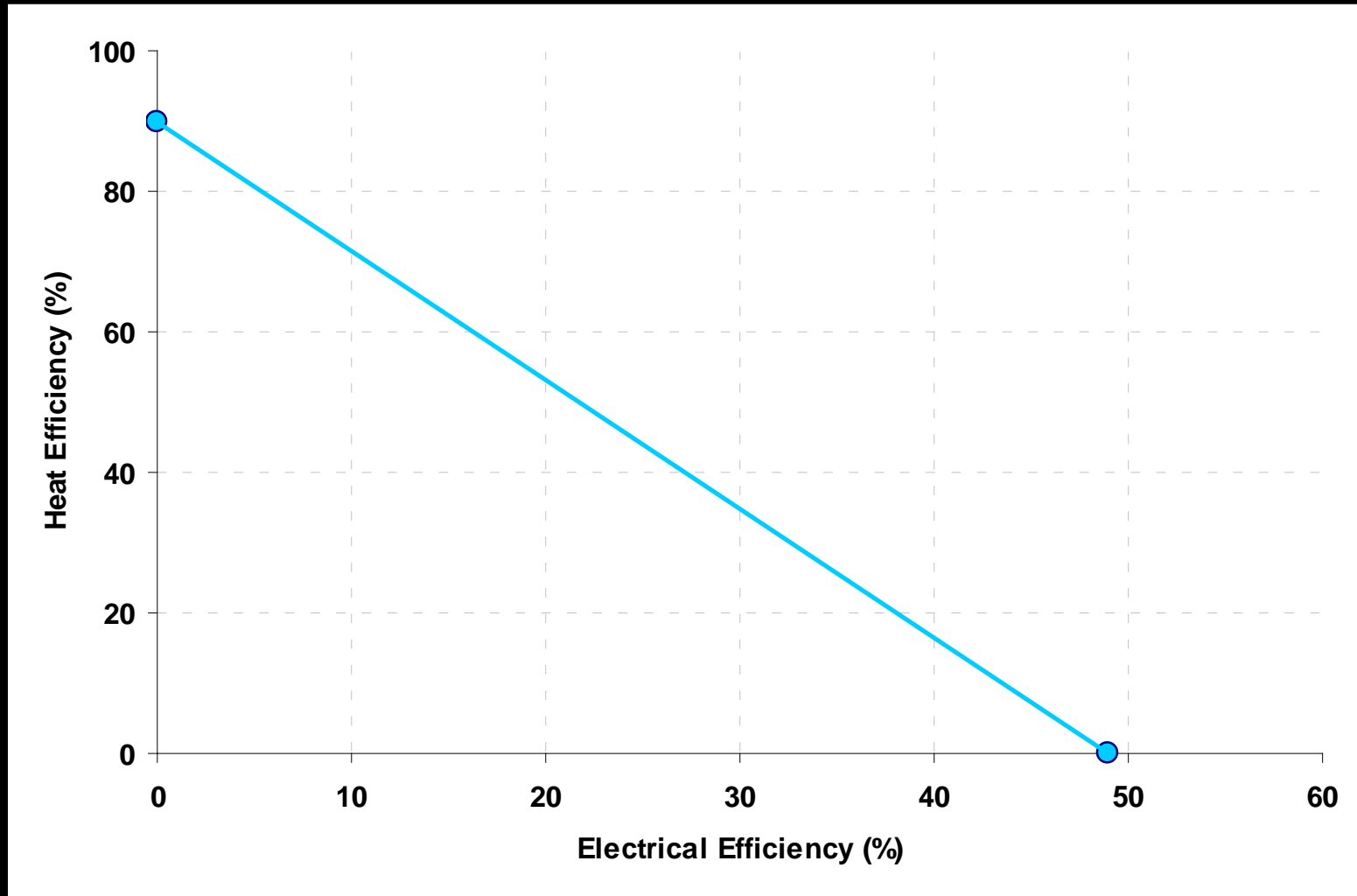
# CHP Scheme Performance (for Natural Gas)



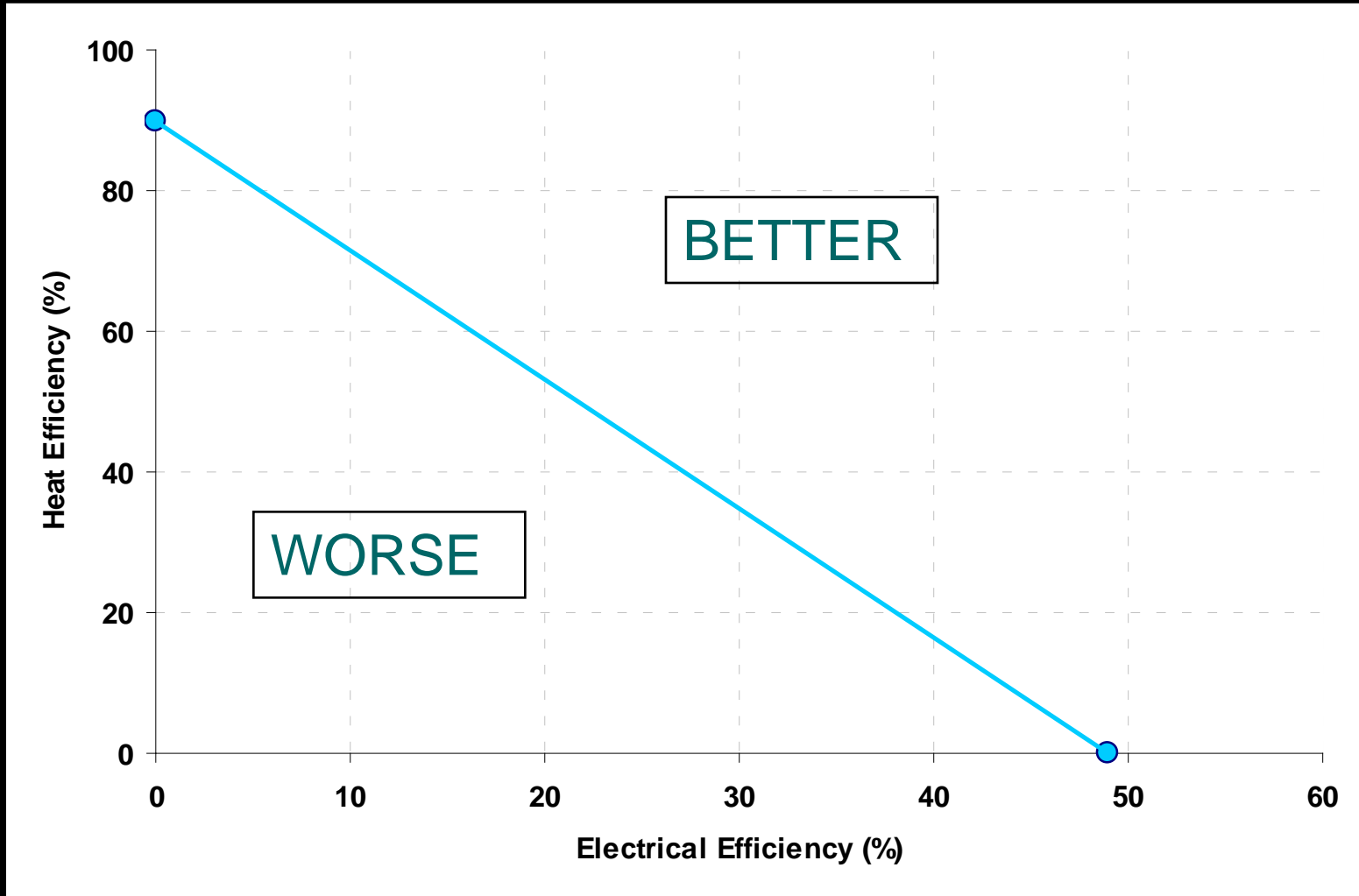
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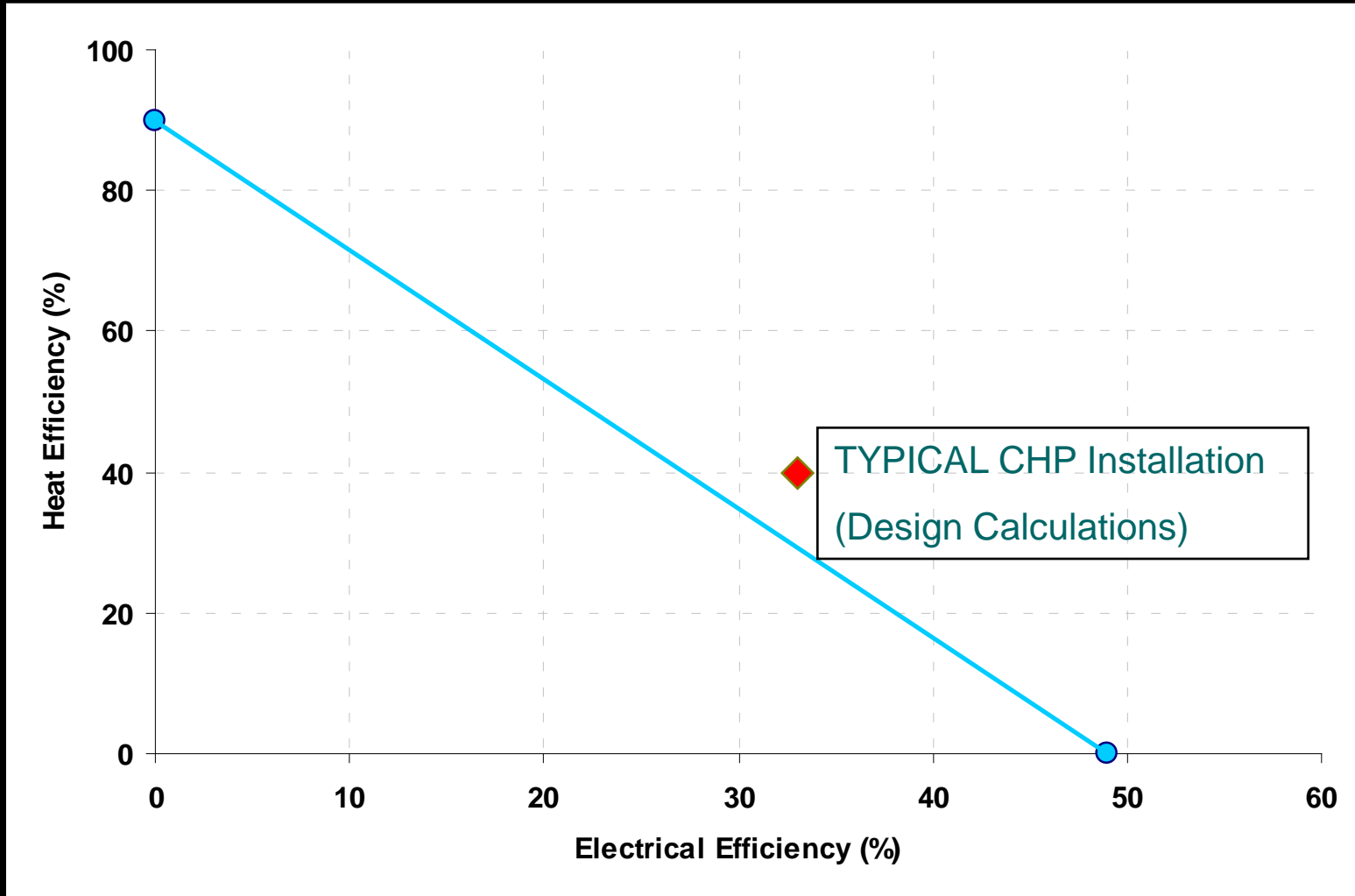
# CHP Scheme Performance (for Natural Gas)



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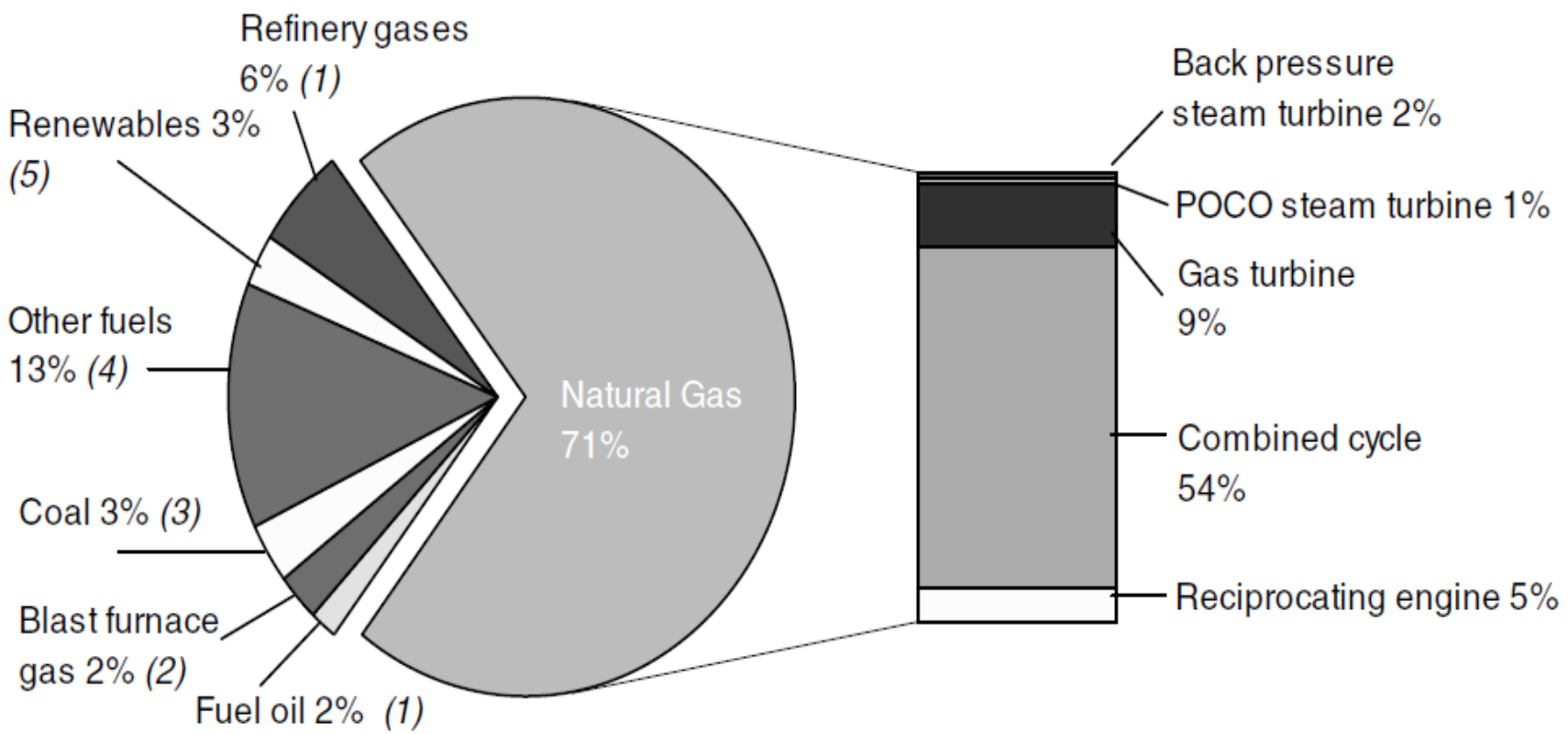


# CHP Scheme Performance (for Natural Gas)



So.....how do existing (2007) 'Good Quality' CHP installations rate when compared to the EU Directive / CHPQA ?

**Chart 6.2: Types of fuel used by CHP schemes in 2007**



**from DUKES 2008**

**Table 6D: A summary of scheme performance in 2007**

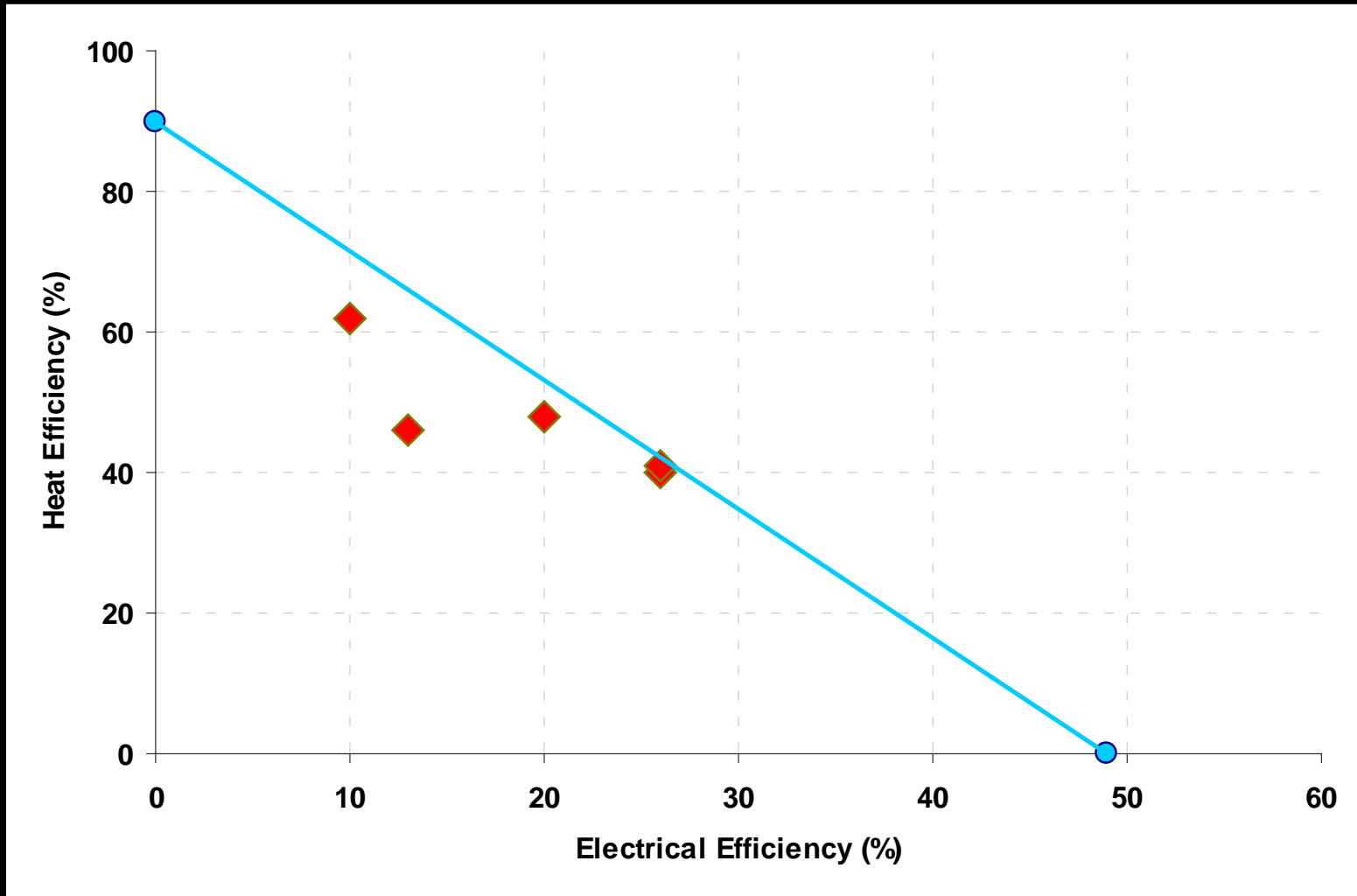
	Average operating hours per annum (Full load equivalent)	Average electrical efficiency (% GCV)	Average heat efficiency (% GCV)
<b>Main prime mover in CHP plant</b>			
Back pressure steam turbine	4,420	10	62
Pass out condensing steam turbine	3,730	13	46
Gas turbine	5,300	20	48
Combined cycle	5,745	26	40
Reciprocating engine	3,357	26	41
<b>All schemes</b>	<b>5,239</b>	<b>23</b>	<b>43</b>

**from DUKES 2008**

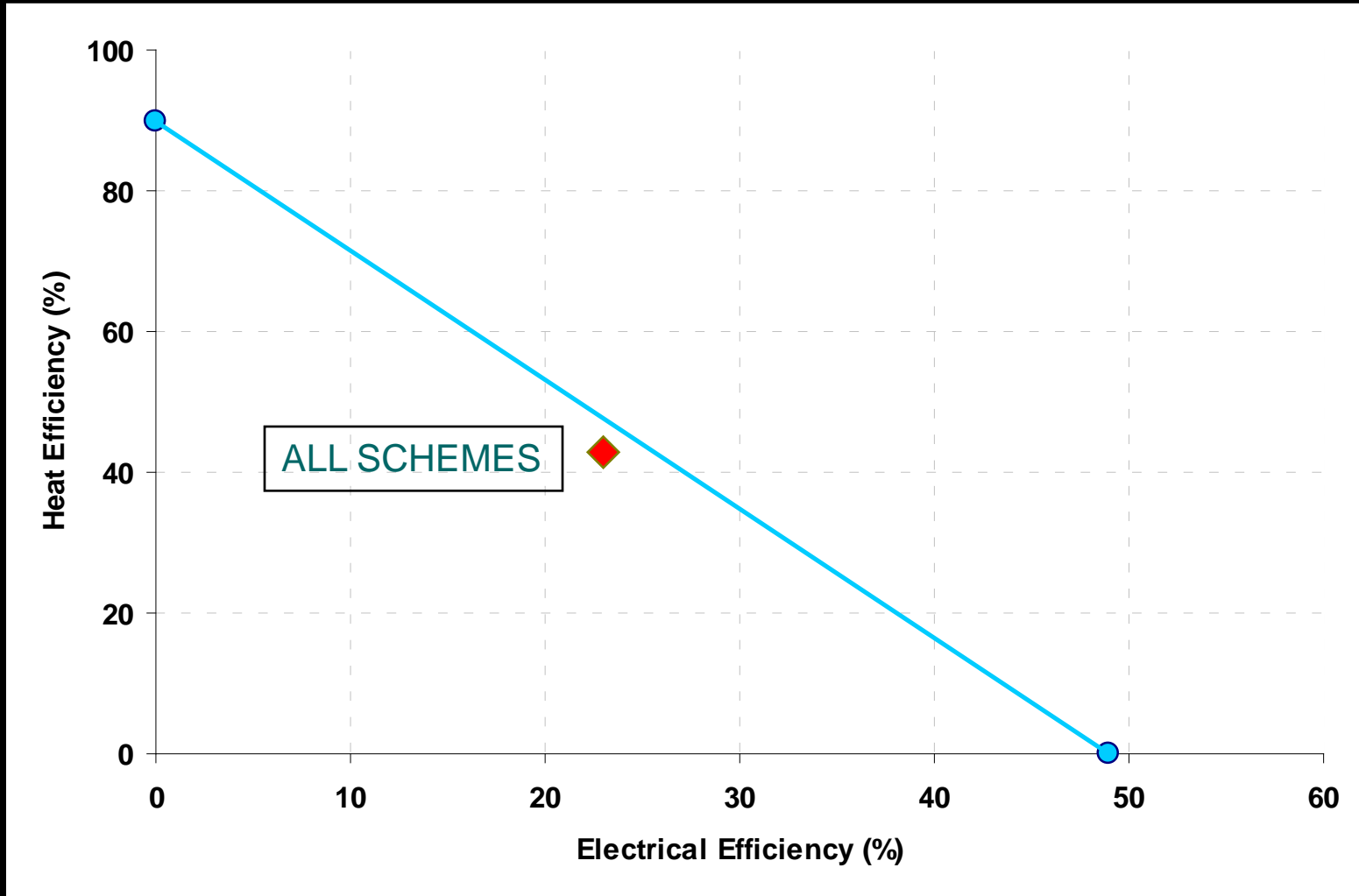
# 2007 Primary Energy Savings against CHPQA reference factors for UK average Good Quality Gas fired CHP systems

	Electrical Eff:ncy %	Heat Eff:ncy %	Overall Eff:ncy %	Primary Energy Savings
Back pressure steam turbine	10	62	72	- 12 %
Condensing steam turbine	13	46	59	- 29 %
Gas Turbine	20	48	69	- 4 %
CCGT	26	40	67	- 1 %
Reciprocating Engine	26	41	68	0 %
ALL Schemes	23	43	67	- 4 %

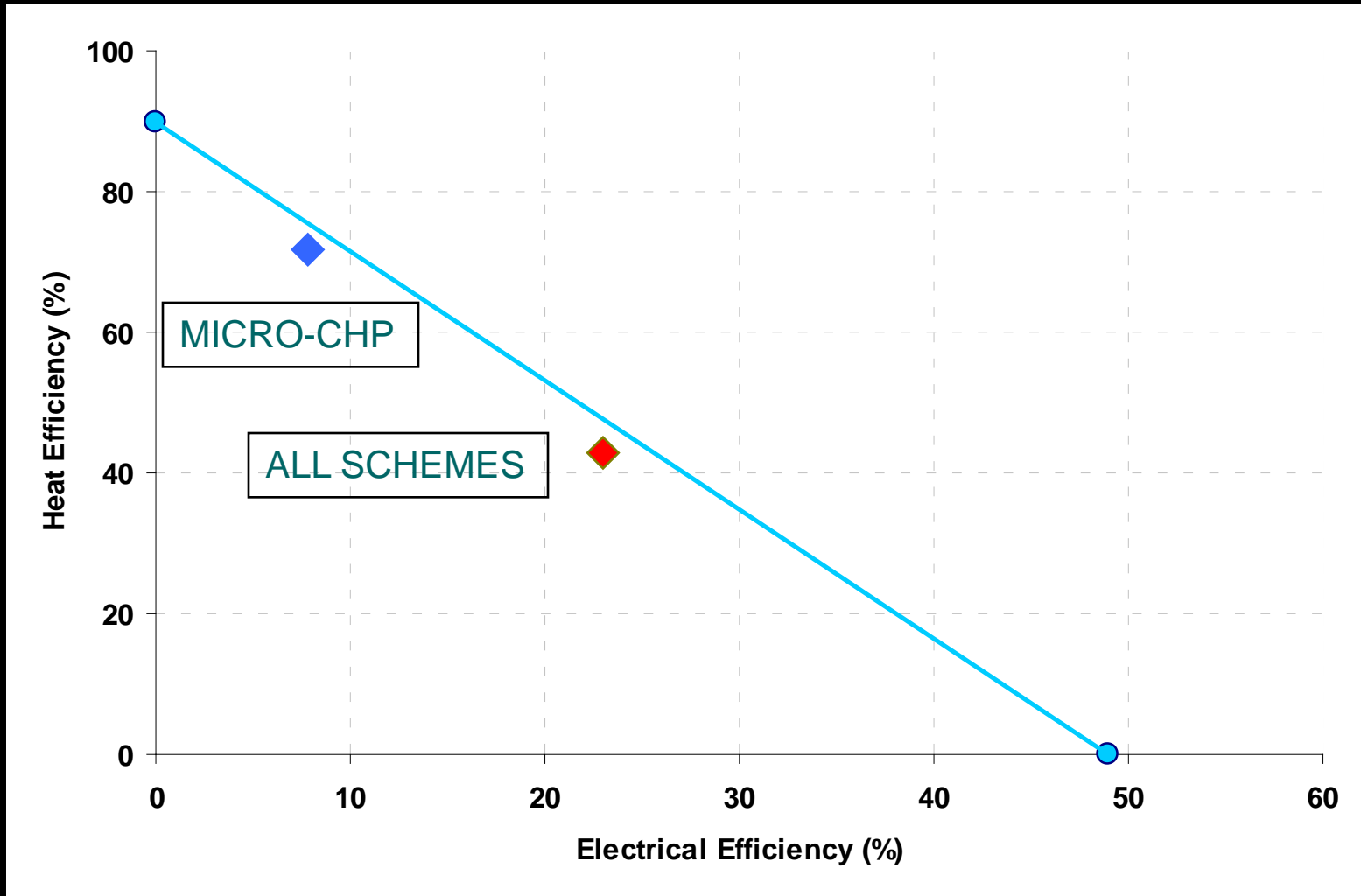
# CHP Scheme Performance



# CHP Scheme Performance



# CHP Scheme Performance



# How has Government been persuaded that CHP is such an efficient Technology?

**There are several methods :-**

- 1. Start by pointing out how inefficient Coal Fired grid is**
- 2. Do not count the heat lost in Heat Network transmission**
- 3. Do not count the heat dumped**
- 4. Do not count the parasitic electrical losses**
- 5. Use test results instead of average installed**
- 6. The overall efficiency trick**
- 7. The wrong reference value trick**

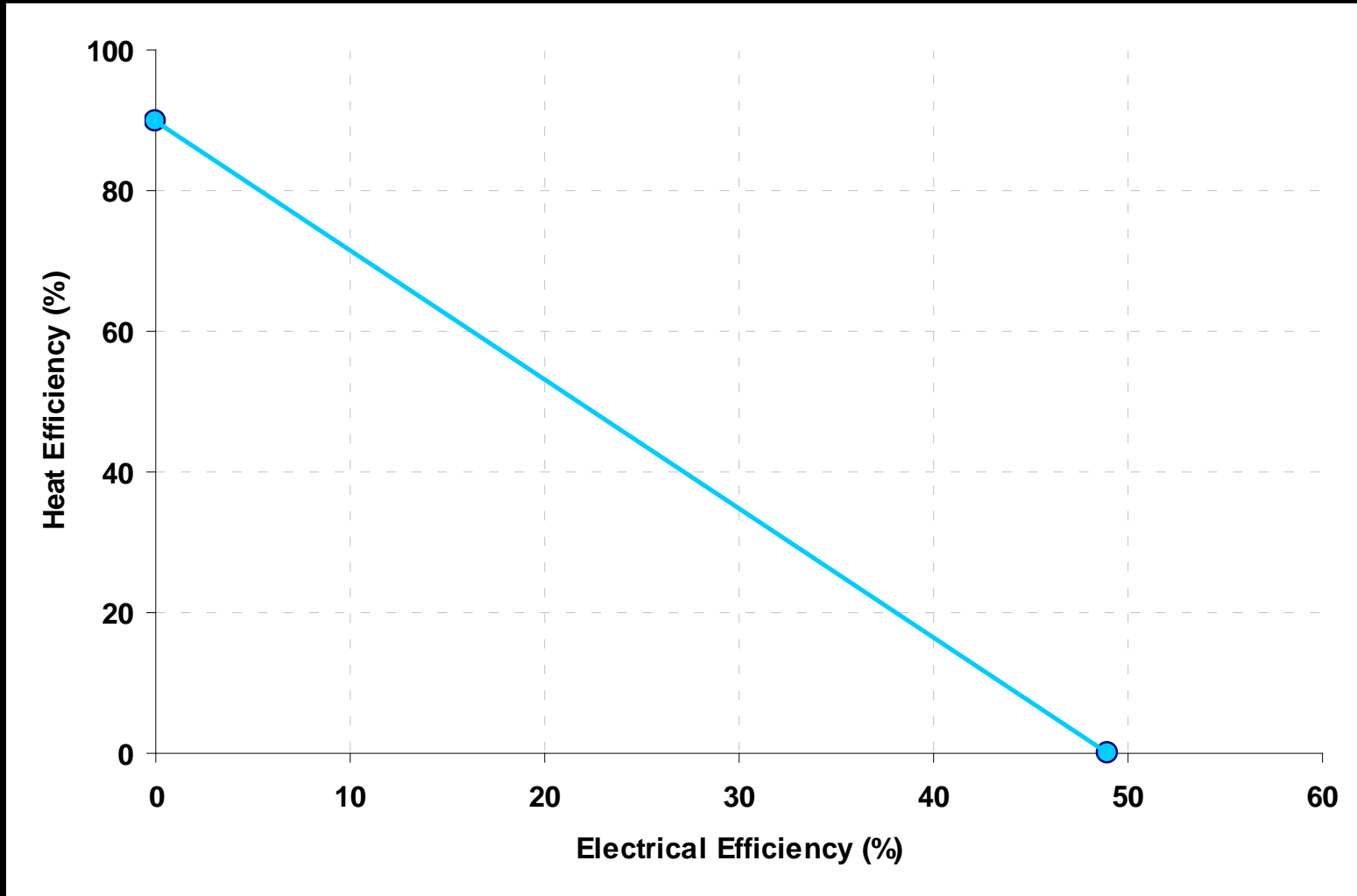
# The Overall Efficiency Trick

This involves adding the percentage useful electricity to the percentage useful heat .

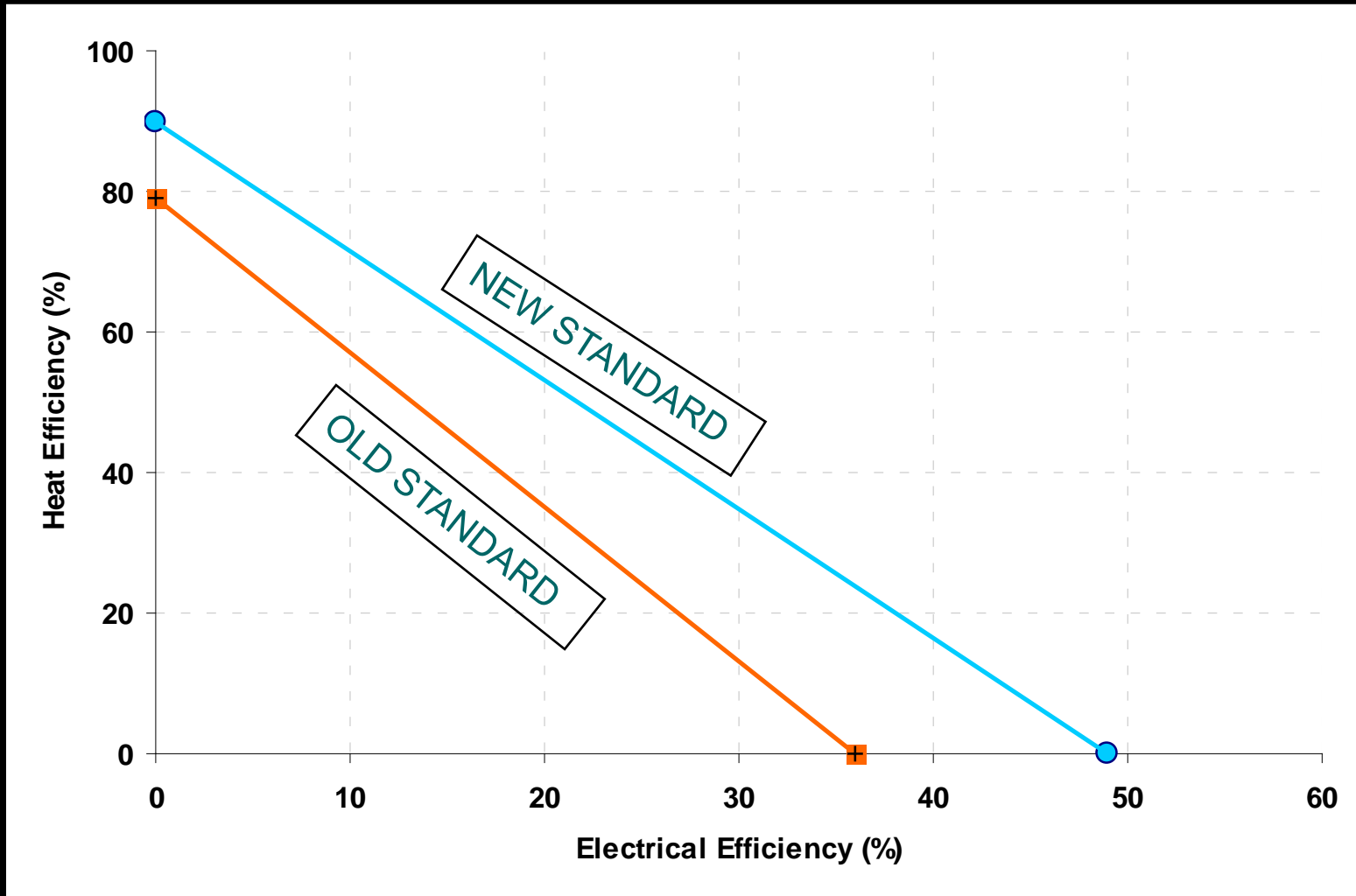
This is then compared to the electrical efficiency of the grid supplied electricity.

	Electrical	Heat	Total
<b>CHP</b>	<b>33 %</b>	<b>40 %</b>	<b>73 %</b>
<b>Conventional</b>	<b>49 %</b>	<b>90 %</b>	

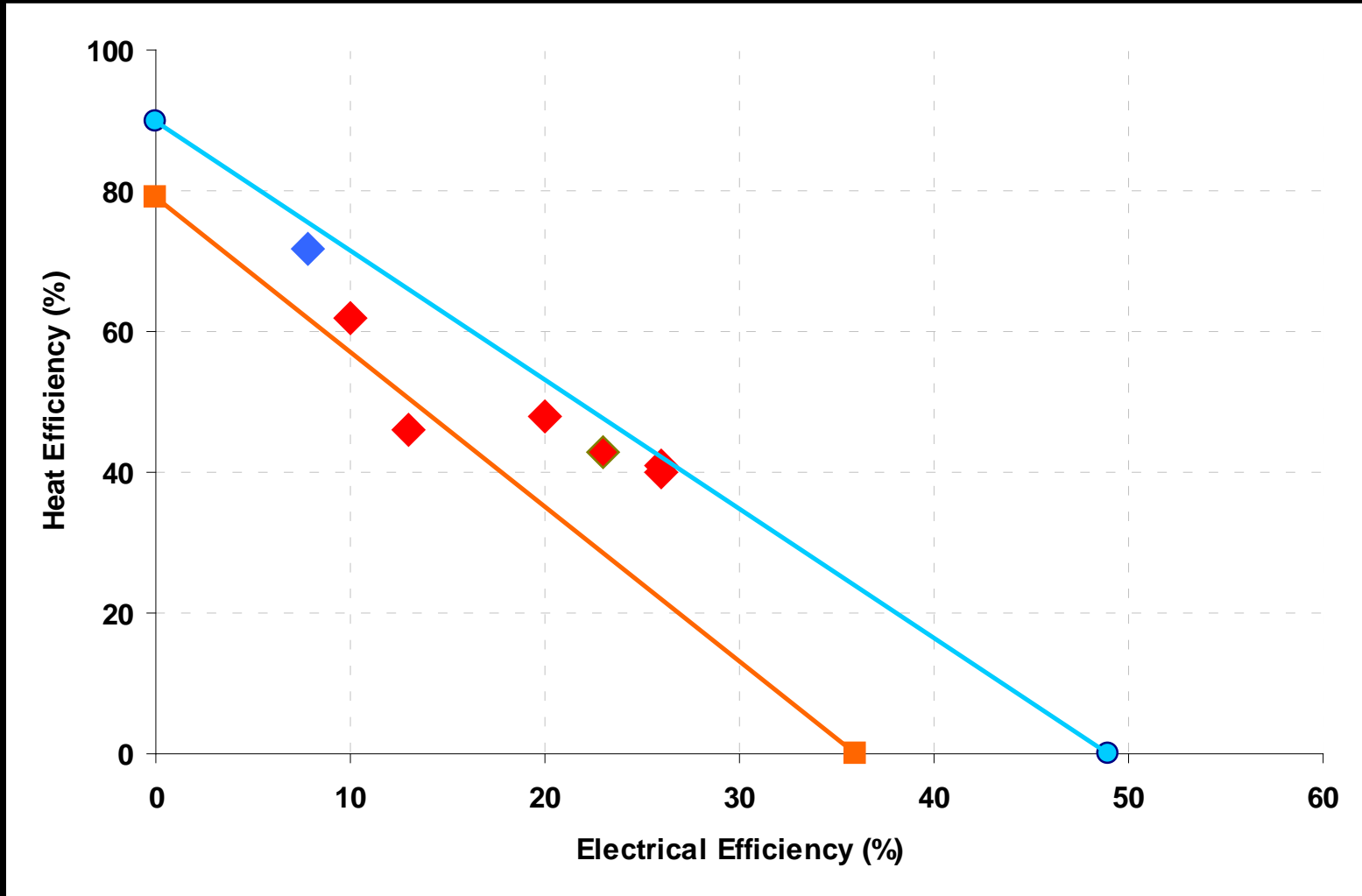
# The wrong reference value trick



# The wrong reference value trick



# The wrong reference value trick



Using this 'wrong reference value' philosophy I have decided to buy a new car.

Jeep Cherokee

222 gCO<sub>2</sub>/km



Lamborghini

500 gCO<sub>2</sub>/km



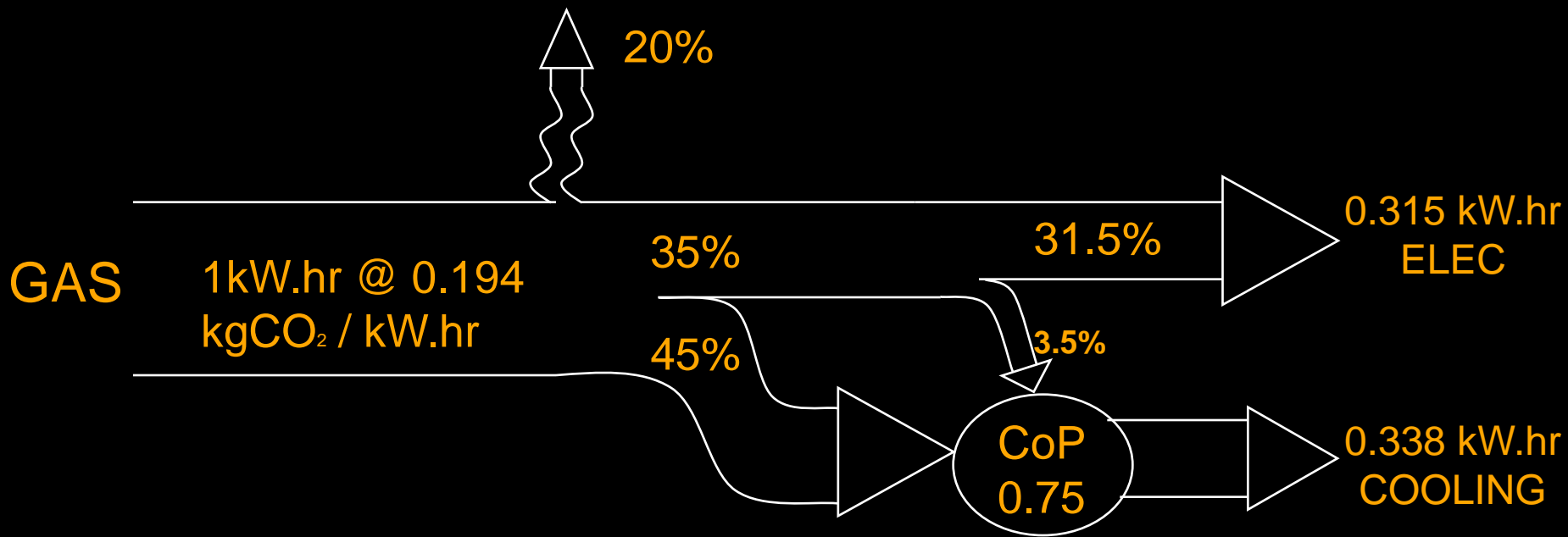
Every kilometer I drive saves 278 g CO<sub>2</sub>

The more I drive, the more Carbon I save !

Who thinks that this is a Confidence Trick ?

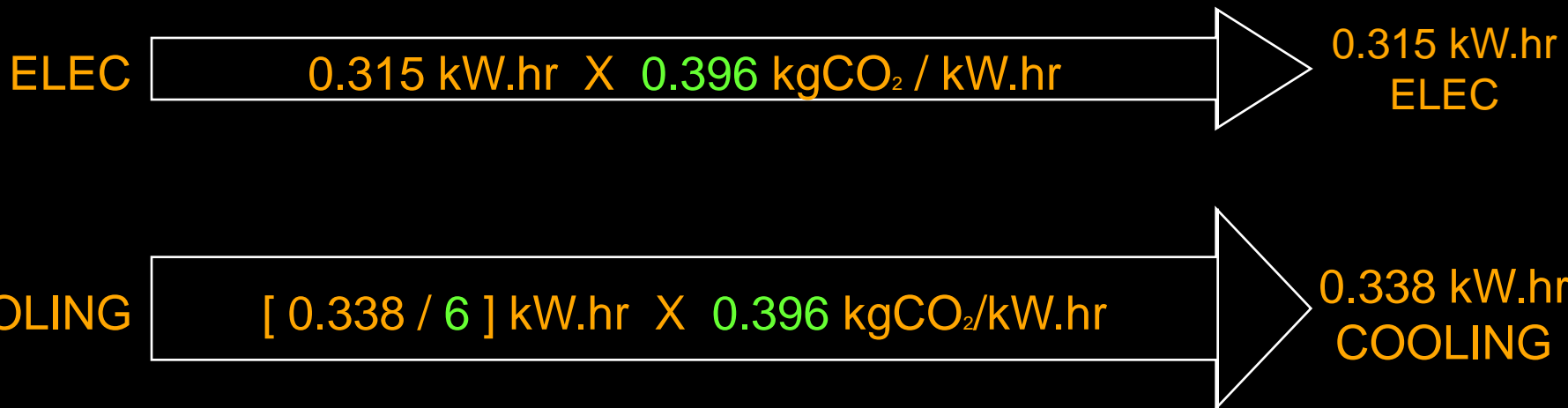
# Combined Cooling and Power

# Typical Gas Fired Co-Generation (Cooling + Power)



$$\text{CO}_2 \text{ Input kgCO}_2 / \text{kW.hr} = 1 \text{ kW.hr @ } 0.194 = 0.194 \text{ kg.CO}_2$$

# Cooling and Electrical Supplied from Grid assuming Chilled Water CoP of 6



$$\text{CO}_2 \text{ Input} = [0.315 \times 0.396] + [(0.338 / 6) \times 0.396]$$

$$\text{CO}_2 \text{ Input (Conventional)} = 0.146 \text{ KgCO}_2$$

$$\text{CO}_2 \text{ Input (CCP)} = 0.194 \text{ KgCO}_2$$

# Proposal for calculating the Primary Energy Savings (PES) for Combined Cooling and Power Co-Generation Schemes.

## Cogeneration, Combined Cooling and Power Energy Savings

Primary energy savings are calculated as follows:

$$\text{PES} = \left( 1 - \frac{1}{\left[ \frac{\text{CCP } C\eta}{\text{Ref } C\eta} + \frac{\text{CCP } E\eta}{\text{Ref } E\eta} \right]} \right) \times 100\%$$

Where

PES = Primary Energy Savings.

CCP  $C\eta$  = the cogeneration cooling efficiency is defined as the annual useful cooling output divided by the fuel input used to produce the sum of useful cooling output and electricity from 'combined cooling and power' plant.

Ref  $C\eta$  = the efficiency reference value for separate cooling production.

CCP  $E\eta$  = the cogeneration electrical efficiency is defined as the annual electricity from the plant divided by the fuel input used to produce the sum of useful cooling output and electricity.

Ref  $E\eta$  = the efficiency reference value for separate electricity production

# Typical Combined Cooling & Power (CCP) summary

CCP scheme

0.194 CO<sub>2</sub>

Conventional Reference: 0.146 CO<sub>2</sub>

CCP Scheme is 33%  
more energy intensive

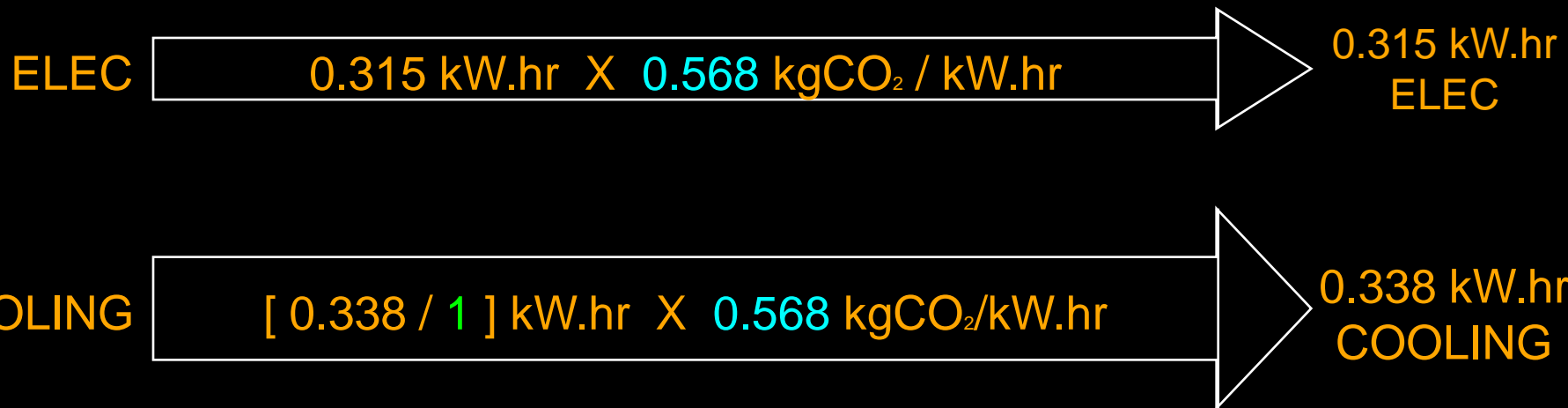
So, why do so many operators and Councils claim that Tri-Generation saves energy?

**There are several methods :-**

- 1. Do not count the heat / coolth lost in transmission**
- 2. Do not count the heat dumped**
- 3. Do not count the parasitic electrical losses**
- 4. Assume that the heat used for cooling is used efficiently**
- 5. Use test results instead of average installed**
- 6. The overall efficiency trick**
- 7. The wrong reference value trick**
  - Electricity
  - Heat
  - Conventional Chiller Coefficient of Performance

# The Wrong Reference Value Trick

Cooling and Electrical Supplied from Grid assuming BERR Part L Grid Displaced electricity factor and Cooling Reference CoP of 1



$$\text{CO}_2 \text{ Input} = [0.315 \times 0.568] + [(0.338 / 1) \times 0.568]$$

CO <sub>2</sub> Input (Wrong reference)	=	0.371 KgCO <sub>2</sub>	254 %
CO <sub>2</sub> Input (CCP Co-Generation)	=	0.194 KgCO <sub>2</sub>	133 %
CO <sub>2</sub> Input (Correct Reference)	=	0.146 KgCO <sub>2</sub>	100 %

# Tri-Generation Case Study – Natural History Museum

**Installed and commissioned in 2006**

**1.8 MWe Gas Fired CHP Reciprocating Engine**

**1.4 MW Absorption Chillers (2 x 0.7 MW)**

**CHP Operational in January 2007**

**Cooling Operational in July 2007**

**CHPQA applied for in December 2007**

# Case Study – Natural History Museum

## 2007 Results - First year in operation

Total Fuel Input	35711 MW.hr	
Total Electrical	11595 MW.hr	32.5 %
Total Available Heat	10830 MW.hr	30.3 %
Total Heat Dumped	1407 MW.hr	3.9 %
Total Heat used for Heating	7432 MW.hr	20.8 %
Total Heat Used for Cooling	1990 MW.hr	5.6 %
Total Cooling	1207 MW.hr	CoP = 0.61
Total Primary Energy Savings		- 10.4 %

# Case Study – Natural History Museum

<b>Results</b>	<b>2007</b>	<b>2008</b>
<b>Total Fuel Input</b>	<b>35711</b>	<b>37946 MW.hr</b>
<b>Total Electrical</b>	<b>32.5 %</b>	<b>32.8 %</b>
<b>Total Available Heat</b>	<b>30.3 %</b>	<b>31.1 %</b>
<b>CHP Primary Energy Savings</b>	<b>0 %</b>	<b>1.5 %</b>
<b>Total Heat Dumped</b>	<b>3.9 %</b>	<b>4.5 %</b>
<b>Total Heat used for Heating</b>	<b>20.8 %</b>	<b>12.7 %</b>
<b>Total Heat Used for Cooling</b>	<b>5.6 %</b>	<b>13.9 %</b>
<b>Total Cooling</b>	<b>1207</b>	<b>2812 MW.hr</b>
<b>Total Primary Energy Savings</b>	<b>- 10.4 %</b>	<b>- 19.6%</b>

## SUMMARY

**Consuming Fossil Fuel inefficiently does not save Carbon.....it's a fact.**

**Use the CHPQA to determine whether a Co-Generation installation is more efficient than conventional supply.**

**If a Co-Generation installation is less efficient than conventional supply (using the same fuel source)..... it cannot claim to save Carbon.**

**It's that simple**

# Tri-Generation and Fossil Fuel Co-Generation

Is it Hype ?

You are Engineers.....do the calculations.

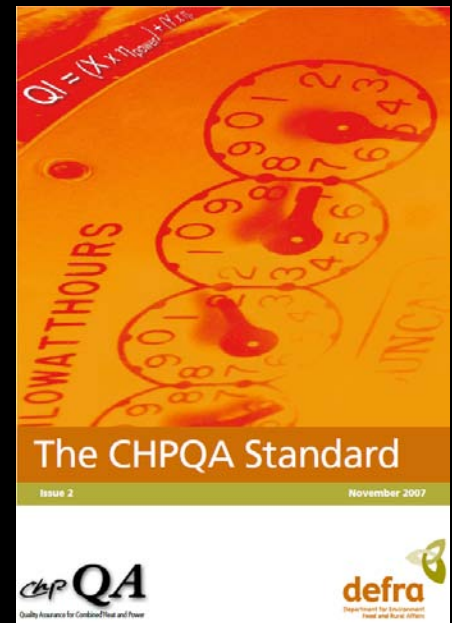
Now, who is going to tell the policy makers that CHP and Trigeneration are unlikely to deliver any significant energy savings?

CIBSE ?, I Mech E ?, Engineering Council ?

What are the Engineering Institutions doing to address Building Regulations inconsistencies with other regulations (notably the CHPQA) ?

Consuming Fossil Fuel inefficiently does not save Carbon.....**it's a fact.**

Thank you for listening



James Thonger

ARUP