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"Discussion of defects in current UK and proposed EU conventions for allocation of fuel burn for power and heat rejected in power generation"

This paper challenges historic and current methods of analysing CHP and questions the common assumption in models and in presentations to decision takers that CHP produces "clean electricity". Every motorist knows that using their power plants heat to keep them warm makes no difference to the fuel consumption to power their journey.

Different power cycles are considered in relation to CHP and their marginal fuel burns for the respective products of heat and power, to illustrate the actuality of the respective fuel burns in practice.

Charts are used to illustrate the effect of different conventions and their assumptions. The most serious anomalies arise for the fuel burn for electricity, if heat is modelled as the prime product, and the assumptions about the overall heat and electricity efficiency of the CHP and a surrogate boiler heat alternative are changed.

Unfortunately heat as prime product has been the assumption used for preparation of statistics by the UK and EU and IEA. It has also been used to model CHP in the WASP model and derivatives of WASP for electricity expansion plans by the World Bank and others, and is still the basis for regulation in some countries and is thought to be the basis used in the recent UK PIU report and the subsequent White Paper on Energy Policy.

The paper proposes a new "Orchard convention" for modelling and regulatory and Energy Policy decisions, that solely addresses comparisons between power plants thus providing a clear regulatory interface for trading on cost or a carbon basis in the respective heat and power sectors.

The paper is presented with a view to reviewing modelling assumptions behind UK CHP policy and possible adoption of the "Orchard convention" as the basis for UK Carbon trading purposes, Part L of the Building Regulations, UK and EU statistics and CHPQA and its EU equivalent.

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1 INTRODUCTION.

CHP is a name given to thermal power generation, when heat that has to be rejected in thermal power generation, is used instead of being wasted.

Use of heat, rejected by the car engine, to heat the car is the example of CHP that is most readily understood. Motorists know that whether the heater is on or off it makes no difference to the fuel required to power their journey.

The author's experience to date is that many models for CHP by governments are based on the assumption that electricity suddenly changes from prime product to waste product, if any of the reject heat from power generation is used in some system or process.

A typical historic example has been the treatment of Drax a large coal fired power station, no different to other large coal fired power stations producing electricity as its prime product and the heat to the cooling towers a waste product.

For the UK and EU energy statistics, if some of the waste heat from Drax instead of going to the cooling towers was used to grow tomatoes, the prime product changed from electricity to heat. The waste heat now was viewed as having been produced from an imaginary boiler with an imaginary fuel burn.

Electricity now the waste product was then credited with the imaginary boilers fuel burn.

The heat instead of being clean renewable with no fuel burn became fuel and carbon intensive.

The result by this method was more efficient electricity production with lower fuel burn cleaner electricity!

Using the motor car as an analogy of a power plant the reasoning behind the statistics would be the equivalent of advising motorists that if they kept their car heater on they could save fuel for their journey!

The author is delighted to note that this method is no longer used; the current methods developed by the DTI are discussed in this paper.

This paper has been written in an attempt to clarify the current confusion in relation to the modelling of CHP and the current carbon trading formulas used by the UK and the complex draft formulas in a proposal for a draft EU directive.

This paper analyses current and older conventions used by the Department of Trade and Industry and the EU for the allocation of fuel and carbon for CHP between heat and electricity and for the preparation of statistics.

The paper identifies a historic flawed assumption that the market alternative to the waste heat from CHP has to be heat from a boiler.

Given that waste heat from power generation is sufficient to heat all major cities in the UK. The appropriate market comparison would be waste heat from alternative power sources.

For perfect market competition surely the alternative heat would come from another CHP?

Some arms of government and the Electricity supply industry argue that heat has to be the prime product from CHP.

When there is competition between CHPs for a market, which product is their prime product?

Is the prime product the higher value product?

Would one ever run a CHP just to supply heat on its own or in competition with another CHP or in competition with a boiler?

What does a marginal analysis of a power plant signal in terms of fuel burn for the respective products when demand changes for one product?

The paper has been stimulated by the author's experience of working with models on energy strategy for ETSU, EBRD, London Economics, Tebodin, ERM and other companies when carrying out energy strategy work for nations or regions[1] where it became clear that decisions associated with CHP depended critically on the assumptions that are made.

EG is it more economic to invest in heating buildings with waste heat to reduce carbon or to invest in retrofit insulation of the building.

2 POWER CYCLES, HEAT REJECTION AT DIFFERENT TEMPERATURES.

[1] Lithuania, Kaliningrad Region, St Petersburg Region, Belarus, Ukraine, Crimea, Kazakhstan (Uskamenagorsk) and Romania. Also major EU project led by Tebodin for 13 PHARE countries associated with Legal and Regulatory issues and CHP.

2.1 Introduction.

There are numerous different power cycles that can be used to produce power. The most common ones are Otto, Diesel, Rankine, Brayton, and Stirling. There are also various fuel cell cycles.

Each cycle has a different characteristic in terms of their power efficiency and the temperatures at which they reject heat.

- **Rejection of heat is an unavoidable part of thermal power production, dictated by the first and second laws of thermodynamics.**

- **All power generation has to invest in a heat load to reject this heat whether the heat load is a cooling tower, a radiator in a building or a process heating in industry.**

2.2 Temperature of heat rejection from different cycles

Some power plants such as Drax, coal fired (Rankine cycle), gas fired CCGT (Brayton cycle then Rankine Cycle) reject the heat at a low temperature suitable for under floor heating and tomato growing. The same cycles operating under different cycle conditions can also reject heat at higher temperatures.

2.2.1 Rankine cycle, change of electrical efficiency and power cycle with heat rejection temperature

The cycle works by converting water to steam with significant heat used just to convert the water to steam at the same temperature (latent heat). The steam then expands from high pressure to low pressure generation power by turning a turbine in the same way as wind drives a wind turbine. The steam then has to be condensed back to water, and to do this, heat has to be taken out of the steam to turn it back to water.

This simplistic explanation of the cycle is given to assist in understanding that whether the heat removed in condensing the steam is put to a useful purpose or to waste makes no difference to the actual power cycle.

For the Rankine cycle a steam turbine power cycle, where heat for the steam is produced in a boiler, one can choose to operate the cycle in a way that rejects heat from the cycle at different temperatures.

The lower the temperature at which the steam is condensed, the more power can be extracted from the steam.

Typically if one chose to operate the cycle to condense the steam and reject heat at 30°C, the efficiency of power production for a 250 MW coal fired module might be say 34%.

If you decide to operate the cycle to condense the steam at 82 °C, the temperature used to heat buildings, the efficiency of power production reduces to around 30%.

In both cases the latent heat of the steam has to be rejected to turn steam back to water as part of the power cycle. This rejected heat can either be rejected to a cooling tower at a low temperature or rejected to heat buildings at a higher temperature.

An analysis was made of the fuel burn that reflected a practical market signal of the fuel burn required to produce reject heat from such a power plant at the higher temperature of 82 °C, when the operator is requested to supply more heat at this temperature of rejection instead of 30 °C.

I.e. the fuel burn required to change the power cycle from heat rejection at 30C to heat rejection at 82 °C.

The analysis resulted in an additional fuel burn per unit of heat produced at the higher temperature of 82 °C, compared to expanding the steam to reject heat at 30 °C of about 0.3 units of fuel per unit of the heat rejected at the higher temperature. This compares with a fuel burn for heat from a boiler of around 1.25 units of fuel per unit of heat.

The economic analysis also showed that there were also small reductions in fuel burn for the power produced when heat was rejected at the higher temperature, particularly under part load conditions where demand for power was low and the turbine was operating on part load.

The example of the Rankine cycle on case rejecting heat at 30°C and in the other case at 82°C illustrates the principle of two power cycles using the same fuel, where the higher efficiency power cycle is compared, to the lower efficiency power cycle, producing useful heat. The power cycles are equalised for their power production efficiency by a fuel burn arising for the heat produced at the higher useful temperature.

2.2.2 Peak load gas turbines (Brayton Cycle).

Gas turbines reject heat at high temperatures suitable for steam production or heating buildings.

2.2.3 CCGT

The combined cycles are the Brayton and Rankine cycles the waste heat from the gas turbine being used to raise steam for the Rankine cycle.

An interesting aspect of the analysis of the cycle is that on part load for the overall CCGT, rejection of heat at a useful temperature from the steam turbine part of a CCGT, will improve both the steam turbine and the gas turbines power cycle efficiency on part load. The gas turbine will benefit on account of its poor part load performance

2.2.4 Diesel power plants (Diesel Cycle), Gas Engines (Otto Cycle).

These can be more efficient power producers than large coal or oil fired power plants, often serve smaller electrical systems.

Diesels reject heat at a high enough temperature in the exhaust to raise steam. Heat at a temperature suitable for heating most buildings is rejected from the engine jacket. Heat at a temperature suitable for under floor heating and horticulture is rejected from their oil cooler and intercooler.

2.3 Does use of heat rejected in a specific power cycle change the fuel burn for the cycle's power production?

The following questions are 'food for thought':

What is the difference in the power cycle of a central power plant using diesel engines where heat rejected is discharged to atmosphere, and the same power plant with the same heat captured and distributed to heat buildings?

What is the difference in a motor car's power plant (Otto cycle) when the car's heater is turned off and when the car's heater is turned on to heat the passengers?

Can a motor car reduce its fuel consumption for its journey depending on whether its car heater is on or off?

As far as power cycles are concerned, the laws of thermodynamics dictate there is no difference to the fuel required for power cycles, whether the heat that has to be rejected in the cycle is used or wasted.

How can a decision to use some of the heat rejected in a power cycle change the fuel requirement for the power production?

2.4 Link between efficiency of power cycles and cost of power?

Is there always a link between the efficiency of different power cycles Fuel Cell, CCGT, Rankine cycle coal fired plant, Diesel etc and the cost of the power?

The cost of power whether mechanical or electrical tends to be driven by such factors as:

Capital cost of power plants of different types.

- Maintenance costs.
- Load factor.
- Availability.
- Economies of scale
- Cost of fuel or energy to be converted to power.
- Return on capital required.
- Suitability of the power cycle for the fuel or thermal energy or other energy to be used. (Not easy to burn coal in a diesel engine).
- Efficiency of conversion of thermal energy to power.

If we consider some sample cycles, the Fuel Cell can produce heat at temperatures suitable to heat buildings and with a power efficiency greater than CCGT. The cost of power from the fuel cell is, however, higher than the cost from CCGT due to capital cost influence.

Large diesel engines can produce power at higher power efficiency than a steam turbine Rankine cycle power plant burning coal or oil. Diesels also reject heat at a temperature suitable to heat buildings. Cost of power from the diesel power plant based just on fuel costs can be lower than the Rankine power plant, but higher after maintenance and other costs for the diesel plant are included.

The Nuclear power plant (Rankine cycle) has a very low efficiency for conversion of the heat produced from the reactor to power. Its capital and other costs are high and its overall power costs, depending on assumptions about cost of capital and decommissioning, can be very high or lower than more efficient Rankine cycle coal fired plants. The short run marginal power cost however from nuclear is considered to be lower than many other power producers despite its very inefficient power cycle.

The Stirling cycle used for (micro CHP) has a very low efficiency of conversion of heat to power and high temperatures for reject heat. The cost of power is high compared to other sources due to its low efficiency of conversion of fuel to power even before capital and maintenance costs are considered.

These and other examples illustrate that there is no real link between the efficiency of different power generation cycles, the temperature at which the heat is rejected in the cycles and the cost of power. Efficiency of conversion of fuel or energy to power is only one factor in the equation.

Given that there is no real link between the different factors that influence cost of power and usefulness of heat rejected in power cycles, the author questions why efficiency is the sole parameter being used to encourage the use of waste heat from power production.

Concentration on efficiency alone is unlikely to optimise allocation of economic resources in displacing carbon through CHP and could well discourage use of waste heat from lower cost power cycles and result in increased carbon emissions.

2.5 Actual fuel burn for power and heat in power cycle using marginal fuel burn approach.

An analysis of any power plant will show that the initial fuel burn in the power plant creates sufficient power to overcome the friction and auxiliary power for the power plant.

A marginal analysis can then be conducted to evaluate the respective changes in fuel burn for changes in demand for the respective products heat and power.

Such an analysis shows that normally there is waste heat with a zero fuel burn available before any useful power can be produced.

Increases in demand for power then require a further fuel burn independent of whether the reject heat is used or rejected to waste and an increase in heat rejection.

Analogy: “Does your car heater heat you just as well when stopped at traffic lights as on the motorway?”

An increase in demand for heat even when converting any extra power required directly to heat through electrical resistance heating, is normally not as economic as converting the fuel directly to heat in a boiler on account of friction losses and other losses in the power production process and the extra capital cost of the power unit.

How has the idea developed that heat from CHP is the prime product if all thermal power cycles have to have a heat load to reject to in order to produce power?

The actuality of a marginal analysis in an actual power cycle and its heat rejection is a useful tool to evaluate various conventions used to model heat and power production and is invaluable for taking operating decisions once capital is sunk for owners of CHP.

3 CONVENTIONS FOR FUEL ALLOCATION POWER AND HEAT.

3.1 Convention “Electricity as waste product in power production” “heat prime product”. Electricity industry approach and Russian “Physical” allocation method

The motor car and its heater example illustrates that there is no saving in fuel for a journey when the car heater is used.

However it has been the practice (Russian Physical Method) to pretend that if the waste heat from the car engine had not been used then fuel would have had to be burnt to heat the car using a boiler.

This imaginary fuel burn is then taken off the actual fuel used by the car to show a lower fuel burn for the journey i.e. a cleaner power!

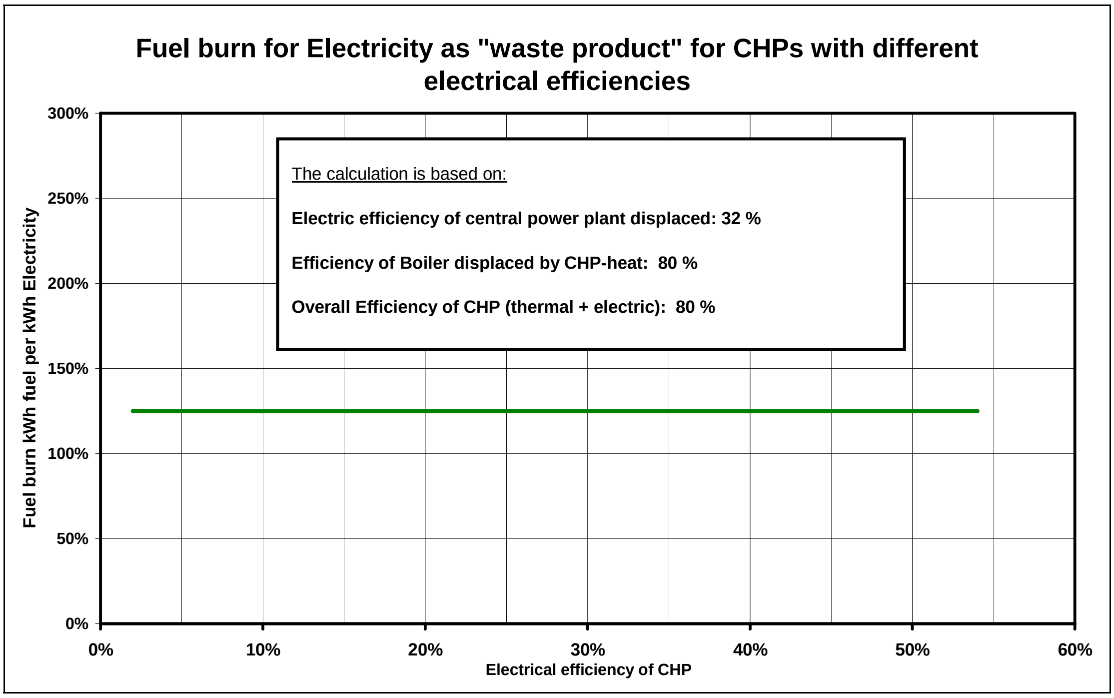
This is the basis of the “Electricity as Waste” convention.

This convention has been enshrined in UK statistics for reporting on and analysing CHP, until this year when it was changed to a revised convention which unfortunately still introduces smaller surrogate fuel burns for heat in its methodology. See section 3.3.

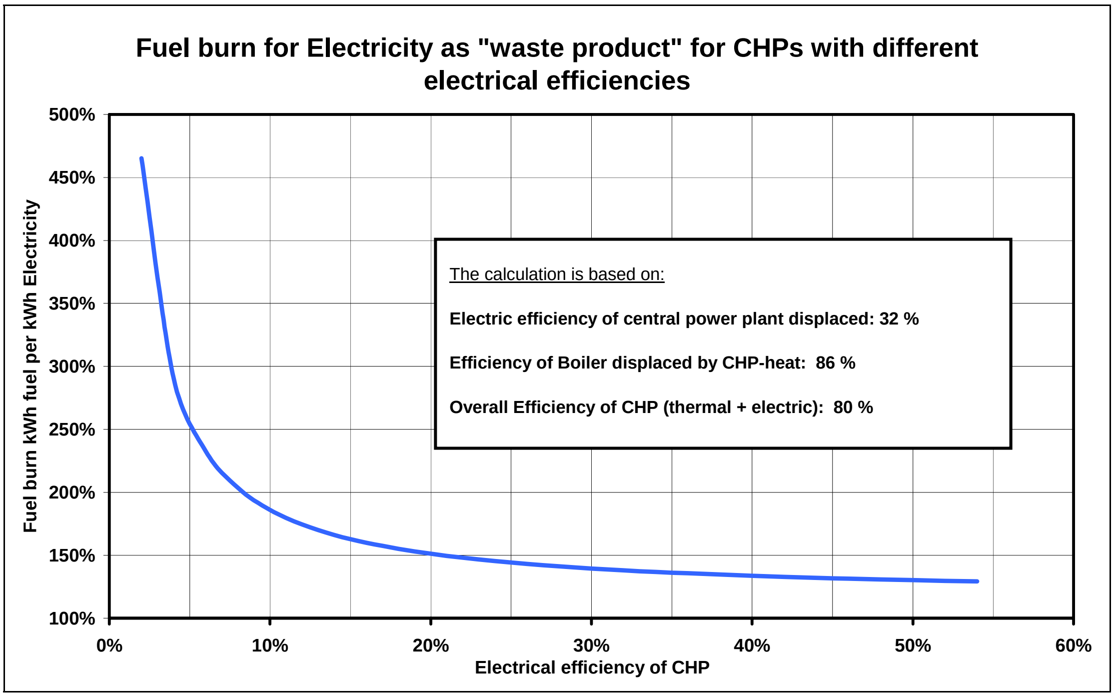
The convention assumes that market competition for the heat sector is modelled by a power plant rejecting useful heat competing against a boiler.

A more appropriate model would be competition between power plants with different cycles for the heat market.

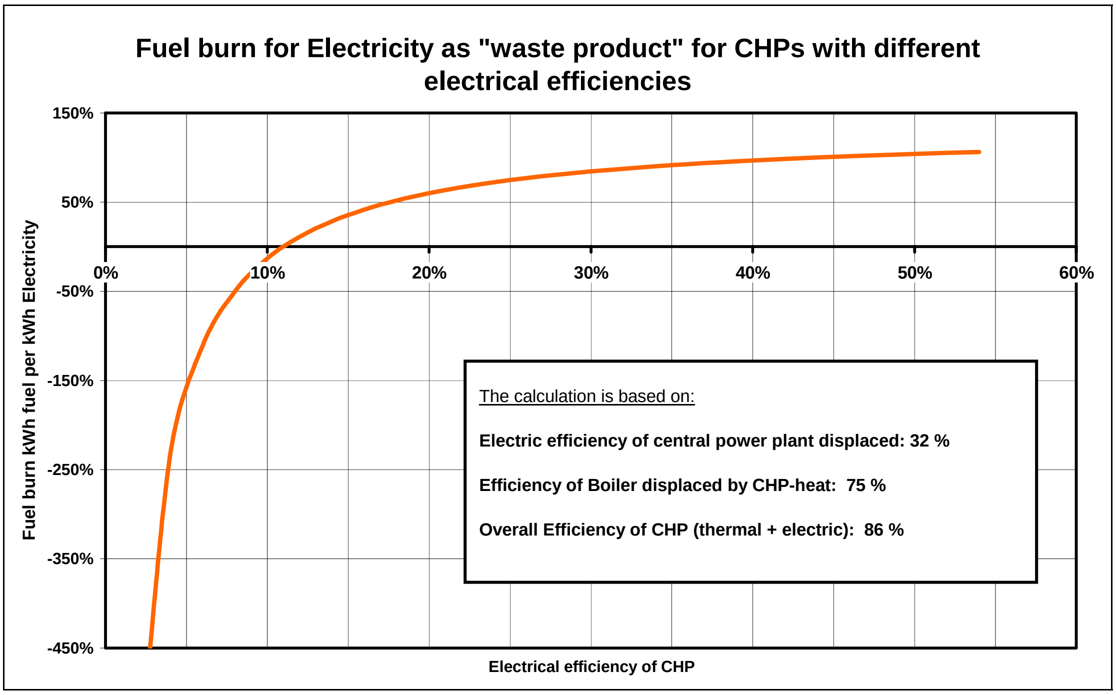
The following graphs headed “electricity as waste product” illustrate the results that arise from the use of this convention for a series of assumptions, and readers can judge for themselves whether they endorse the author’s view that this convention produces absurd results.



3.1.1 Chart 1: Electricity waste product fuel burn for electricity 32(C)/80(B)/80(CHP)



3.1.2 Chart 2: Electricity waste product fuel burn for electricity 32(C)/86(B)/80(CHP)



3.1.3 Chart 3: Electricity waste product fuel burn for electricity 32(C)/75(B)/86(CHP)

Use of the "electricity as waste" convention can produce serious errors in relation to policy advice in relation to CHP as the author discovered when working on energy models for countries with city CHP.

There is strong evidence that this convention was used in the modelling and assumptions that went into the PIU report.

Looking at chart 3 the chart shows that the lower the efficiency of the power production the lower the fuel burn for the electricity signalled by model. Possibly this model is the reason for the anomalous result that low efficiency Micro CHP was superior to larger community heating CHP, a PIU conclusion.

Chart 3 also signals that there is a fuel burn for any heat produced by the CHP and hence losses of fuel when heat is distributed.

It is thought that use of the "electricity as waste" convention was used by consultants modelling CHP and advising the UK government. This would explain the advice that micro CHP was superior to larger electrically more efficient CHP used for community heating.

This author knows from experience that this sort of error will arise when the "electricity as waste" convention is used to model CHP.

This "electricity as waste" convention can not reflect the actuality of market or carbon trading signals. Use of the convention the “Soviet Physical Method” will discourage or prevent reject heat from power generation being used to give carbon displacement in the heat sector. Its effect is to encourage the use of electricity which may explain Electricity industry support for this convention.

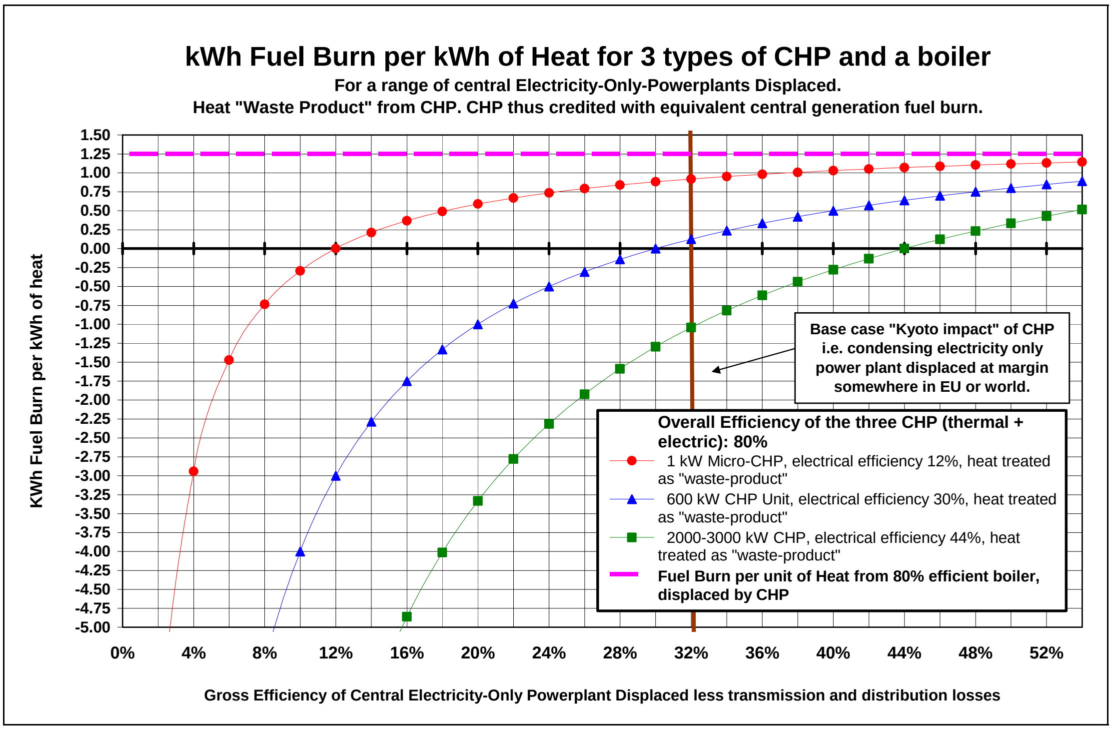
3.2 Heat as waste product convention

This convention treats heat as the waste product when comparing power cycles and reflects the first and second laws of thermodynamics.

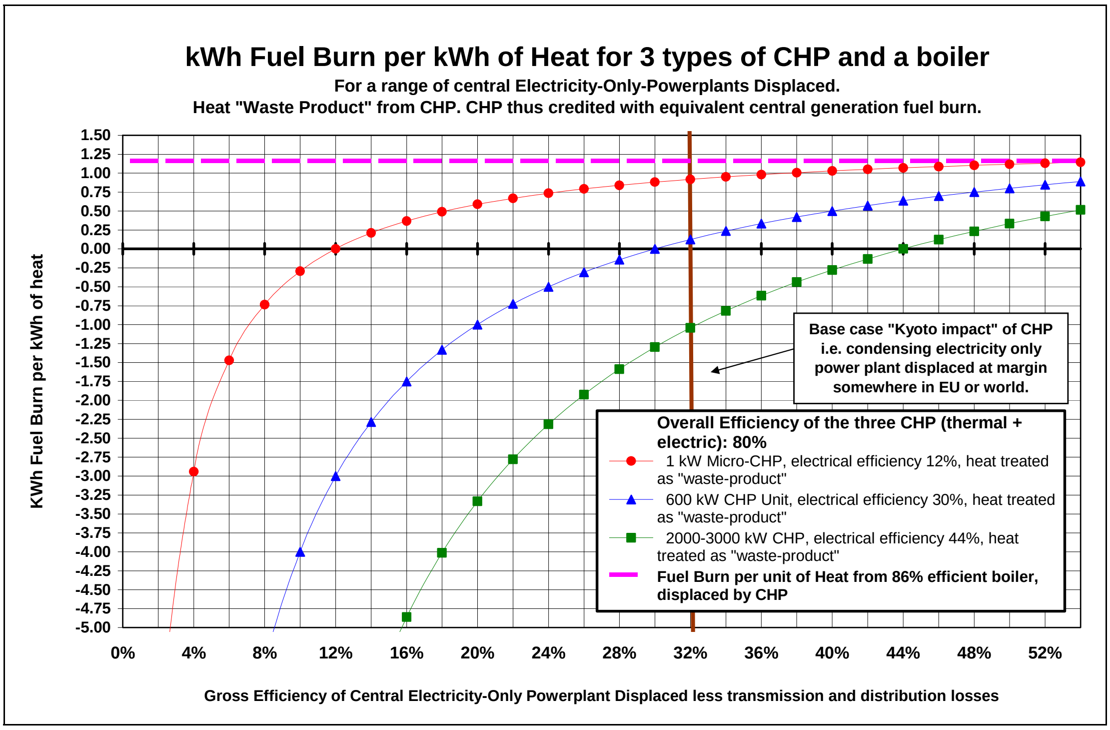
It produces consistent results for the fuel burn required for heat when comparing one power plant against another, and the cross subsidy of fuel burn required from heat (no actual fuel burn for its production) to electricity to account for a lower efficiency of power production in the alternative power plant.

The convention has a disadvantage in that it does not signal the benefit to the power sector when a power plant with a higher power cycle efficiency is compared to the alternative as it generates negative fuel burns for heat.

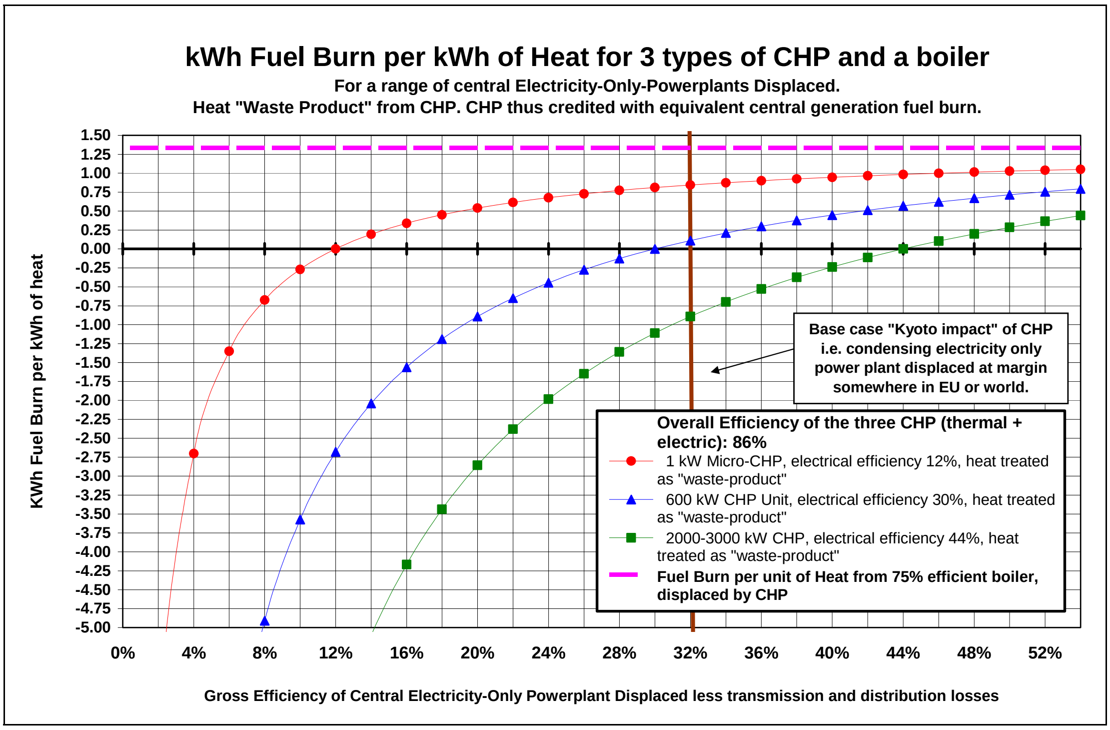
See three charts “Heat as Waste Product”:



3.2.1 Chart 4: Heat waste product fuel burn for Heat. 32(C)/80(B)/80(CHP)



3.2.2 Chart 5: Heat waste product fuel burn for Heat. 32(C)/86(B)/80(CHP)



3.2.3 Chart 6: Heat waste product fuel burn for Heat. 32(C)/75(B)/86(CHP)

The “heat as waste” convention produces results consistent with the laws of thermodynamics when comparing the fuel burn for heat against alternatives in relation to the power cycle. The convention is the basis for the calculations used in the UK building regulations in relation to CHP.

Comparing the results to the “electricity as waste” convention, changing the assumptions in the “heat as waste” convention does not radically change the conclusions, as occurs when the “electricity as waste” convention is used and tested with the same parameters.

Use of this convention accords with the laws of thermodynamics and provides more correct signals of the relative merits of different CHP units to reduce carbon emissions.

As an example in Chart 4 Micro CHP results in a fuel burn of 0.92 units of fuel per unit of heat whereas a better quality CHP (600kW) serving a small community heated estate will give a lower fuel burn of 0.13 units of fuel per unit of heat where both units displace central coal fired generation and its distribution losses.

Assuming the same fuel is used in both central and local generation gas, the better quality community heating CHP gives significantly more carbon savings than Micro CHP for the same heat load.

Neither the “heat as waste”, nor the “electricity as waste” conventions address the issue of the actual fuel burn for power and waste heat in a specific power plant.

The basis for both conventions is to generate surrogate fuel burns, by comparing fuel burns in an alternative method for heat production namely heat production from a boiler, and the fuel burn for power production in an alternative power production cycle.

Neither convention signals correctly the appropriate fuel burn in the respective heat and electricity sectors for power and heat from a specific CHP power plant. This can however be done using an economic approach and calculating incremental fuel burns for changes in demand of the respective products.

The “Orchard convention” proposed at the end of this paper addresses fuel burn for the respective products from power generation without introducing any alternative fuel burn for heat displaced in the heat sector.

3.3 A critique of the current UK DTI convention for CHP Statistics.

This convention is a mixture of the assumption that electricity is a waste product and the assumption that heat is a waste product.

The convention includes an arbitrary assumption that alternative power cycle efficiencies are 50%.

The convention makes the assumption that any heat rejected in the power cycle comes from a surrogate boiler.

The convention makes an arbitrary allocation of fuel used in the power plant between the heat and power in the ratio that two units of fuel are required per unit of power and one unit of fuel per unit of useful heat.

These assumptions do not reflect the actuality of the various power cycles that operate in practice in the power sector. The effect of the convention is to discourage the distribution of heat to displace fuel burn in the heat sector which is unfortunate as it is only the distribution and use of the heat that generates actual carbon savings.

The following charts show the results that arise from the use of this convention.

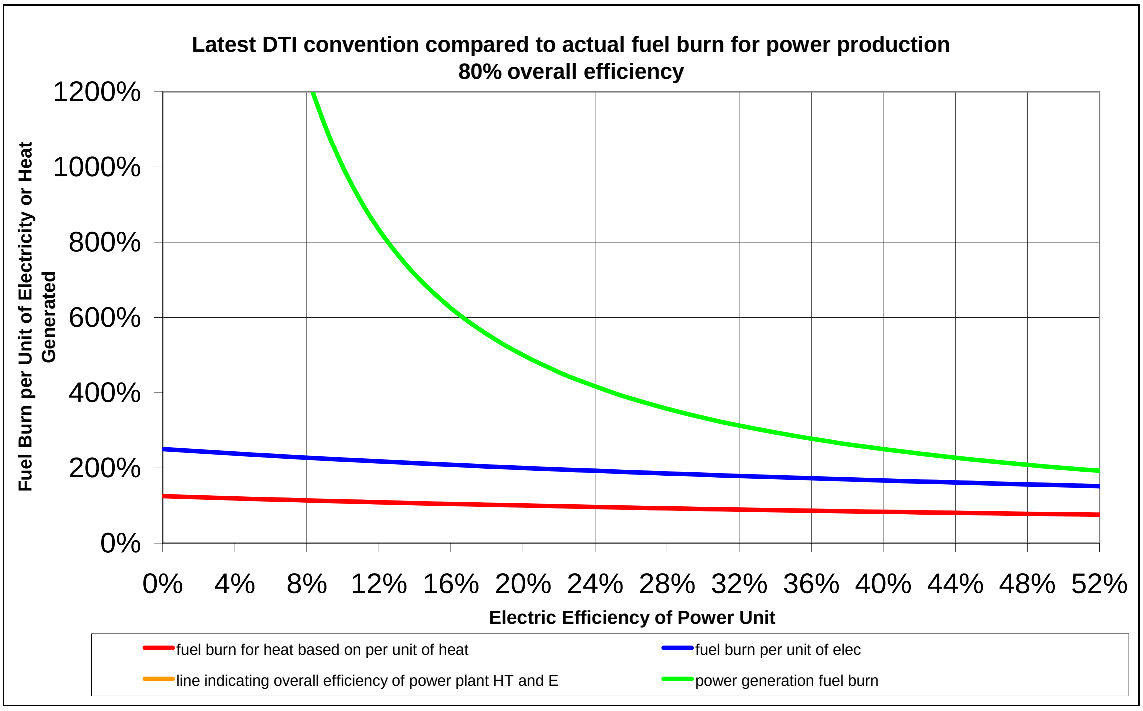
Chart 7 shows the fuel burn per unit of electricity and the fuel burn per unit of heat plotted for normal power production top curve (green) for a range of efficiencies of power production from 0 to 52%.

This top green line reflects fuel burn per unit of power production where heat is just wasted.

The two other curves show the result of the formula for the fuel burn for power production and the fuel burn for heat production where the heat is used and the combination of the power production and the use of the waste heat results in an overall efficiency of 80%.

The curves are plotted as fuel burn per unit of heat and fuel burn per unit of power for a range of electrical efficiencies of the power plant.

Chart 7 Fuel burn for 1) power no heat used, 2) power with heat used, 3) waste heat from power production. Overall useful energy from fuel when heat used heat used 80%.



3.3.1 Chart 7: DTI convention Fuel burn for 1 power no heat used, 2 power with heat used, 3) waste heat from power production. Overall useful energy from fuel when heat used heat used 80%

The convention produces some odd results as can be seen from the graphs.

Inherent in this convention appears to be a double counting of a fuel burn that can not be recovered for heat production or power production which explains the rather odd results for a power plant with a close to zero electrical efficiency.

The convention produces the result that a motorist driving a car with an engine efficiency of say 24% will incur a fuel burn if the car heater is used, a result that does not accord with actuality. The fuel for power production in the car is signalled as reducing from four units of fuel to two units. The author trusts that the reader will agree that this result is absurd as it does not accord with actuality.

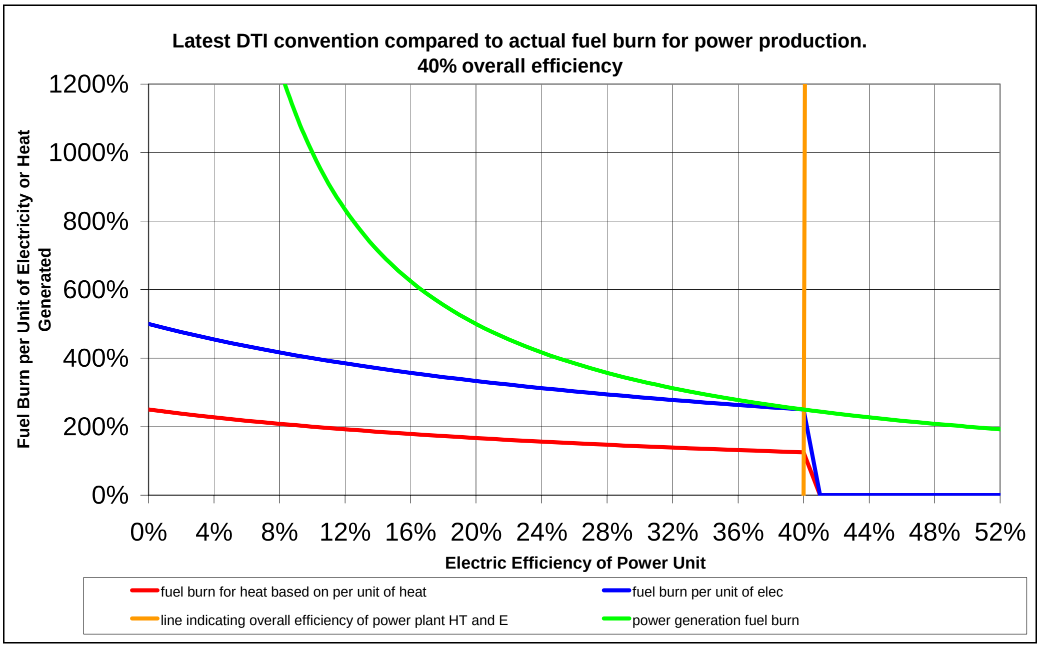
The convention also produces the result that does not accord with actuality that whatever heat is rejected in power generation of any efficiency, even the surrogate 50% efficiency assumed in the modelling, the waste heat always has a fuel burn associated with it.

For power plants of very low actual electrical efficiency close to zero i.e. virtually a boiler, the convention produces the very odd result of a fuel burn per unit of electricity of over two and a fuel burn per unit of heat that is greater than one. An odd result!

The convention never signals the zero fuel burn benefit from using waste heat understood by motorists.

Even heat from a fuel cell with a power efficiency identical to or greater than the efficiency of a CCGT when producing heat at a temperature that can be readily used is allocated a fuel burn and a carbon burden.

Let us now consider the effect of using less waste heat from power generation for a useful purpose and see how the DTI convention works for this condition.



3.3.2 Chart 8: DTI convention Fuel burn for 1 power no heat used, 2 power with heat used, 3 waste heat from power production. Overall useful energy from fuel when heat used heat used now 40%

Readers are asked to consider the credibility of the results from Chart 7 and the signals given about use of heat from CHP.

The convention is effectively a variation on the electricity as waste convention. Signalling, as can be seen from the charts, huge reductions in fuel burn for power when heat is used.

Fuel burns for heat, which are greater than fuel burns for heat from boilers for power cycles of low efficiency, are signalled, thus discouraging use of waste heat from such power cycles where they are economic for reasons other than efficiency

Under conditions of low electrical efficiency as the unit approaches a boiler in terms of performance, very odd high figures arise for the fuel burn per unit of heat.

The convention signals that there is little or no benefit in distributing and trading heat from power generation and the power sector to displace heat from other sources in the heat sector.

This does not allow for the consideration of power generation cycles that have different efficiencies of power generation and costs of power production. It defines all power production as having an arbitrary efficiency of 50%.

The convention does not reflect the actuality of power production from the variety of fuels currently used the cost of those fuels and the resulting least cost route for power production.

The convention does not allow market conditions to determine the development of the power market and carbon trading as it makes an assumption about the least cost future structure of power generation. It then pre-empts market competition by requiring new CHP to compete against parameters and assumptions about future power plants instead of letting CHP compete to deliver new capacity for least cost power production as a replacement for older power plants.

The assumption that the central generation assumption is least cost may well be flawed if the models used for evaluating the CHP alternative were based on "electricity as waste assumptions" when considering supplies of heat from CHP as a means to heat cities.

The conclusion from the analysis is that the current DTI convention appears to be unsuitable as a basis for the carbon trading of heat in the heat sector as it does not reflect the actuality of fuel burn for heat rejected in power generation for power cycles that may produce least cost power and heat.

The convention, due to its partial assumptions that electricity is the waste product in power generation derives fuel burns for heat that do not reflect actuality.

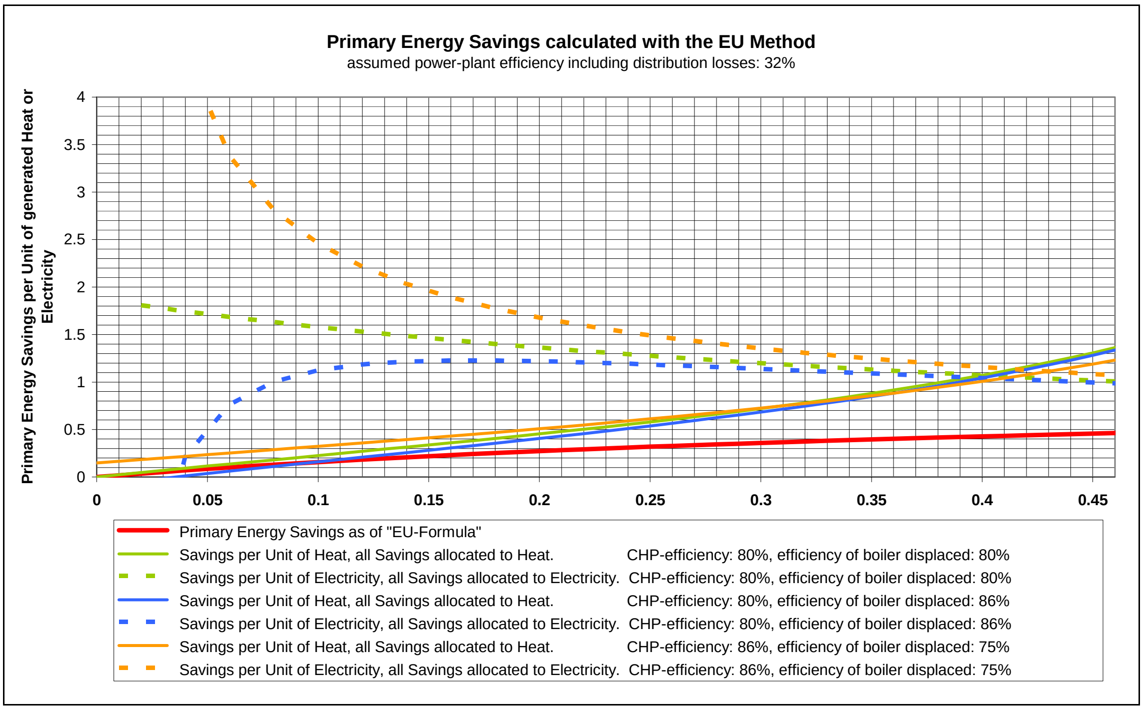
The convention if used to model least cost solutions for the heat sector for CHP will give incorrect results.

The UK may not then meet carbon targets that could be readily achieved through CHP as recommended in the Royal Commission Report. Use of this convention will result in appropriate allocation of the UK's economic resources to meet the climate change challenge.

3.4 A Critique of an EU draft directive convention for CHP.

The EU draft directive and the complex Protermo methodology is based on electricity as waste product heat as prime product assumption and has been promoted to member states and members of the EU Parliament on the basis that CHP produces "clean electricity."

The EU proposals, if adopted, will not give the correct signals for CHP technology to develop and make the contribution it can make to reduce carbon emissions.



3.4.1 Chart 9: EU Draft directive convention. The primary Energy Savings calculated with the proposed "EU-Method" (red) and the effect if these savings are allocated to the electricity or heat alone for different CHP types (remaining lines)

By plotting the primary energy savings calculated using the EU formula and then by allocating the savings for the same examples as used in earlier charts, Chart 9 illustrates the effect of treating electricity as the waste product in power generation.

The EU convention effectively cross subsidises power production from heat production through its surrogate fuel burn for heat assumptions and does not properly reflect the carbon savings in the respective heat and electricity sectors.

Like the other conventions it derives its different results for the fuel burn for electricity and heat by considering the fuel burns in alternative heat and power producing systems.

To obtain results from the formulas used in the conventions, the fuel burn in an alternative boiler is required. Boilers can have a variety of fuel burns and we do not see why it is necessary to have any knowledge about fuel burns for alternative heat production to calculate the fuel burn for heat rejected in power generation.

The “Orchard convention” described in the following section provides information on the fuel burn for heat by only considering power cycles and comparing one power cycle to another power cycle.

We believe that adoption of the “Orchard convention” would resolve many of the disagreements about the Protermo system whilst providing a sound basis for the support of CHP by the EU as well as providing a simple and robust basis for carbon trading in the two respective sectors the “heat trading sector” and the “power trading sector”.

3.5 New “Orchard convention”

The new Orchard convention considers power cycles and compares different power cycles and any use made of heat rejected as part of the power generation process.

The Orchard convention, since it is all about comparison of power cycles allocates fuel to the electricity and heat generated in the following way:

All fuel is initially allocated to the electricity; no fuel is allocated to the heat. This reflects the fuel burn for electricity whatever happens to the waste heat. Fuel burn for electricity is high if the electric efficiency of the power plant is low.

When comparing one power plant against another, the maximum fuel burn per unit of electricity is then set to a surrogate fuel burn to match the fuel burn of a benchmark or alternative power plant. A difference then arises between the actual and surrogate fuel burns. This difference is allocated to the amount of waste heat that is used.

The efficiency of the benchmark power plant is set according to local conditions and political requirements, and can be altered as technology advances and political requirements change. (The benchmark limit basically ensures that the electricity generated by power plants with a lower electric efficiency than the benchmark power plant has no higher fuel burn than that of the benchmark power plant itself.)

The benchmark also signals fuel savings for power production as power plants that have a higher electric efficiency than the benchmark power plant are signalled as having a zero fuel burn for the heat and any benefit of reduced fuel burn for power production is signalled for the power sector.

A major benefit of the convention is that it does not need to make any assumptions about the fuel burn or carbon content of alternative sources of heat displaced by the use of the waste heat from power generation.

The convention provides information on a “surrogate” fuel burn for any heat used for power cycles which are deemed to have an inferior efficiency of power production through the setting of an arbitrary benchmark efficiency of power production.

It accepts that different power cycles have different efficiencies of power production and costs of power and that there is no link between cost and efficiency of fuel conversion.

E.g. Fuel cell: high cost, high efficiency; Nuclear: high cost, low efficiency.

The convention also signals the carbon benefit or fuel burn benefit of using a more efficient power cycle to displace existing power cycles and thus gives a signal to the electricity and power sector of the benefit of using more efficient power cycles.

The new convention uses three inputs:

- (A) The electrical or power efficiency of a power production process.

- (B) The overall efficiency of the power production and heat production process where the heat used has been measured.

- (C) The electrical efficiency of an alternative “benchmark” power production process used to compare power efficiencies and calculate a surrogate fuel burn for heat used to equalise power production efficiencies.

The electricity industry and electrical consumers are particularly concerned that if power cycle “A” that rejects heat at a low temperature suitable for horticulture is changed to a power cycle “B” that produces heat at a higher temperature suitable to heat buildings will result in an increase in cost of power to electricity consumers.

Unfortunately there is no simple link between cost and efficiency of power production or price for power.

Where waste heat from power production is being used there is no link between any surrogate fuel burn for the heat, the cost of the heat and the price the heat can command.

The convention can be used to reflect current conditions in the power sector and allows least cost solutions to develop without having to predict what future costs and the efficiency of the most likely future power generation technology might be. A limitation of a number of other conventions.

The convention thus addresses power cycles and their reject heat and provides a flexible frame work for the carbon trading of waste heat from power generation to the heat sector without disadvantaging the power sector.

The convention provides a surrogate fuel burn for the heat rejected in a power generation cycle where countries wish to restrict the utilisation of waste heat by setting a defined standard for power production efficiency for different categories of power generation as a benchmark.

As an example, the efficiency of power generation from coal, oil or gas is limited if the Rankine cycle is used. Higher efficiencies can be achieved in other cycles e.g. CCGT for gas, a cycle not suitable for nuclear or coal.

The convention can thus be operated in a way that allows factors other than just the efficiency of power production to be taken into account. These factors can be more critical for least cost power production and national security of energy supplies than efficiency.

The convention can thus be used by changing the benchmark efficiency (input three) to encourage use of waste heat from nuclear or coal fired plants where the short run cost of power may be low but when capital and operating costs are considered the long run cost may be higher than alternative power sources such as CCGT.

The convention leaves the actual carbon or fuel displaced in the “heat sector” to be traded in the market place as one element in the overall economics of utilisation of waste heat from power generation in the heat sector to reduce carbon emissions.

The principles of the convention are much simpler and more flexible than the “Prothermo Methodology” as it allows regulators to take into account a number of factors in setting the appropriate benchmark to be used.

The following charts illustrate the “Orchard convention” and show how the same convention can be used to give appropriate signals for different power plant cycle efficiencies and overall efficiencies of power and heat production.

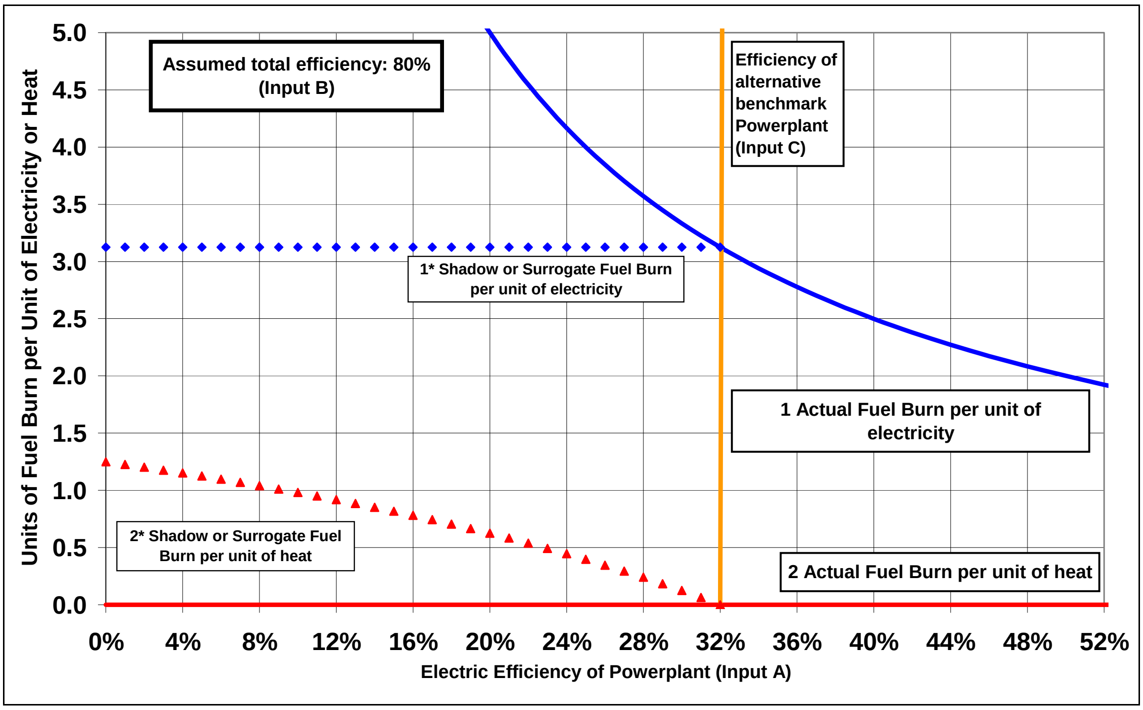
Chart 10: illustrates the results from the convention for local embedded power cycles close to points of consumption of electricity compared to a benchmark power cycle with a delivered efficiency of power production of 32%. (Benchmark efficiency, input three to the convention.)

This benchmark has been selected as reflecting a typical case in many countries in the world where power production is centralised, using Rankine cycle coal or oil fired power plants with an average efficiency over the year of 35% based on the gross calorific value of the fuel and with transmission and distribution losses of 10%.

Input A is reflected on the chart on the x axis for a range of power plants with efficiencies from 0% to 52%.

Input B, the overall efficiency of the power plant, is not shown on the chart but is used in the spreadsheet calculation process to derive the fuel burn per unit of heat.

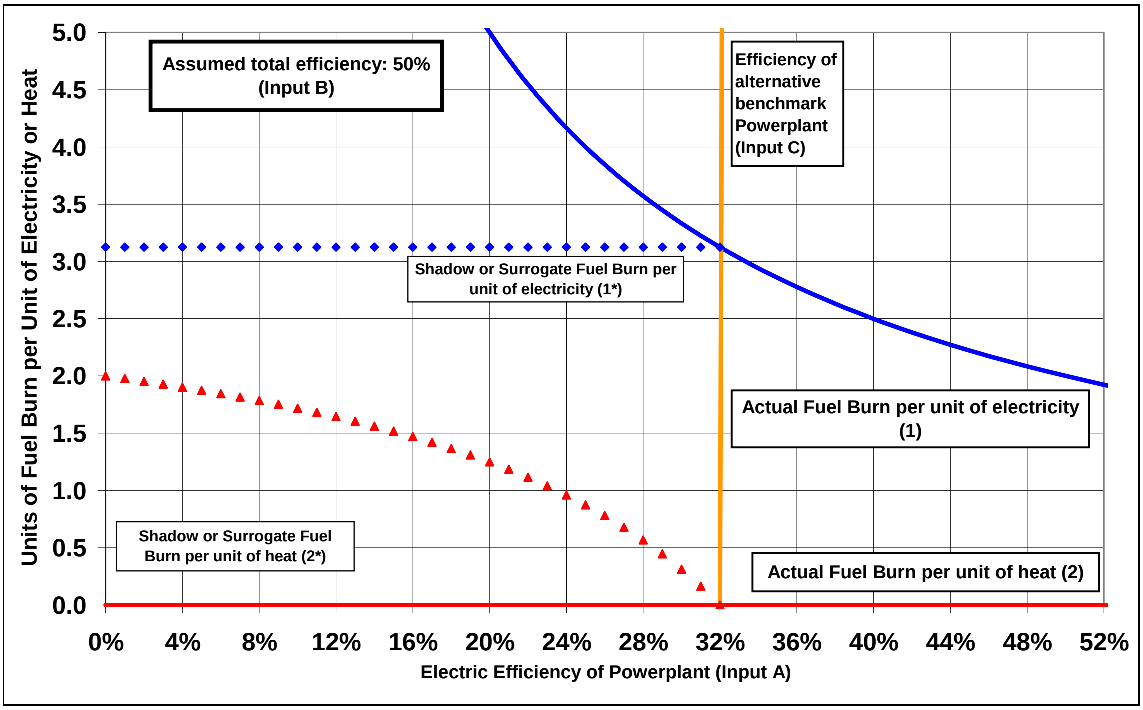
Input C the benchmark alternative power plant efficiency is indicated by the vertical line at 32% signalling the comparative bench mark power plant.



3.5.1 Chart 10: Orchard convention. Showing actual and surrogate fuel burns for energy efficiency and carbon trading incentives. Overall efficiency for power and heat 80%

The next chart, by comparison, shows the same situation with a power plant having an overall efficiency of 50% (input B). It can be seen that the situation on the right side of the orange line, representing a higher electric efficiency than the efficiency of the benchmark power plant, has not changed. This is because the fuel burn here is only dependent on the electric efficiency of the power plant, which is plotted along the X-axis of the chart and does not change. In the area to the left of the orange line, the ("surrogate") fuel burn per unit of electricity is defined as being the same as that of the benchmark power plant, and thus identical in both charts. The effect of the change to the lower overall efficiency is that the surrogate fuel burn per unit of heat, becomes much higher if the total efficiency is lower (chart 6). This is because the remaining fuel, not allocated to electricity, is allocated to a smaller amount of heat.

Obviously, with an electric efficiency of 0%, all the fuel has to be allocated to the heat. This can be seen on chart 6, where the fuel burn per unit of heat becomes 2 with zero electricity output and an overall efficiency of 50%.



3.5.2 Chart 11: Orchard convention. Showing actual and surrogate fuel burns for energy efficiency and carbon trading incentives. Overall efficiency power and heat 50%

3.6 Table showing equations for “Orchard convention”

The following equations show how the lines on the charts above are generated. The principle is simple.

For any specific power cycle reflects actuality and is treated as having no fuel burn for its rejected heat.

For any specific power cycle the fuel burn is allocated to the power sector. Any improved efficiency of power production compared to the benchmark is thus always signalled to the power sector.

Where there is a requirement to compare power cycles and a cycle producing useful heat has a higher fuel burn per unit of power, and thus a lower power efficiency compared to a benchmark alternative power cycle, then a surrogate or shadow fuel burn for the heat produced is developed to equalise the power production fuel burn and efficiency.

X-axis shows electrical efficiency of power plant **Alternative benchmark power plant shown with electrical efficiency of 32% (orange line)** **Chart lines: actual fuel burn per unit of electricity (blue solid line), (1)** **actual fuel burn per unit of heat (red solid line), (2)** **shadow or surrogate fuel burn per unit of electricity (blue dotted line), (1*)** **surrogate or shadow fuel burn for heat (red dotted line), (2*)**				
INPUT:	$\eta_{el(i)}$	=	Electric Efficiency of power plant, some rejected heat utilised	**(A)**
	$\eta_{tot(i)}$	=	Overall Efficiency of power plant (i) for electricity and rejected heat utilised	**(B)**
	$\eta_{el(Ben)}$	=	Electric efficiency of alternative benchmark power plant	**(C)**
OUTPUT:	$FB_{el(i)}$	=	Actual fuel burn per unit of electricity	**(1)**
	$FB_{th(i)}$	=	Actual fuel burn per unit of heat	**(2)**
	$FB_{el^*(i)}$	=	Surrogate or shadow fuel burn per unit of electricity to equalise fuel burn with fuel burn of electricity of alternative benchmark power plant (applies if $\eta_{el(i)} < \eta_{el(Ben)}$)	**(1*)**
	$FB_{th^*(i)}$	=	Surrogate or shadow fuel burn per unit of heat, to cross subsidise and equalise fuel burn per unit of electricity (applies if $\eta_{el(i)} < \eta_{el(Ben)}$)	**(2*)**
$FB_{el(i)} = \dfrac{1}{\eta_{el(i)}}$				**(1)**
$FB_{th(i)} = 0$				**(2)**
$FB_{el^*(i)} = \dfrac{1}{\eta_{el(Ben)}}$ (applies if $\eta_{el(i)} < \eta_{el(Ben)}$)				**(1*)**
$FB_{th^*(i)} = \left(\dfrac{1}{\eta_{el(i)}} - \dfrac{1}{\eta_{el(Ben)}}\right) \times \left(\dfrac{\eta_{el(i)}}{\eta_{tot(i)} - \eta_{el(i)}}\right)$ (applies if $\eta_{el(i)} < \eta_{el(Ben)}$)				**(2*)**

4 CONCLUSIONS

Many conventions do not accord to the actual fuel burn for power and heat in specific power plants when analysed using an economic analysis evaluating marginal fuel burns for an increase in demand of the respective products.

Links between cost of power and efficiency of power production are tenuous.

Evaluating benefits of reject heat from power production to reduce carbon emissions in the heat sector solely on the basis of efficiency of power production confuses cost thermal efficiency and price issues.

Current conventions have been analysed and their shortcomings identified through graphical presentation of the conventions.

These shortcomings mainly arise from the structure of the conventions and assumptions in the conventions that do not accord with the physical laws that govern power generation, which require heat to be rejected if power is to be produced.

The shortcomings and double counting apparent in some conventions arise as a result of attempting to compare heat and electricity production from a power cycle with heat production from a boiler.

The most serious anomalies arise for the fuel burn for electricity if heat is modelled as the prime product and assumptions about the overall heat and electricity efficiency of the CHP and a surrogate boiler heat alternative are changed.

Many conventions can not handle renewable sources of power and heat and renewable CHP because of the conventions requirement to make assumptions about heat production in boilers to estimate the fuel burn or carbon burden of the heat from CHP.

A new “Orchard convention” convention because it is based solely on power generation cycles avoids these difficulties and provides a sound basis for the development of carbon trading in the respective sectors.

It provides a basis through use of the “Benchmark concept” to encouraging the use of waste heat from power generation by signalling the incentives needed to build power plants using different cycles which reject heat at a temperature that can be used to heat buildings.

In any specific power cycle the fuel burn for the heat as every motorist knows when he uses his car heater can not and does not affect the fuel burn for the journey, i.e. the power.

The fuel burn for the heat is actually zero in any specific power cycle and this does not change depending on whether the heat is used or wasted.

If one wishes to compare efficiencies of power cycles where waste heat is used and the fuel burns for electricity production for the two cycles need to be the same, then the “Orchard convention” develops surrogate or shadow fuel burns for the heat used for such conditions.

These shadow fuel burns for heat can then be used to evaluate fuel savings in the heat sector or the carbon savings in the heat sector by comparing the surrogate fuel burns arising from the use of waste heat from power production to the alternative heat production fuel burn and carbon content whether that heat comes from another power plant a boiler or other heat sources such as solar thermal.

The convention has a significant advantage since it is based solely on comparison between power cycles. It offers a structure for carbon trading of waste heat from power generation at a power heat interface.

Since the convention does not include any assumption about the fuel burn of the heat displaced, the convention allows a market to develop in the heat sector for waste heat from different power sources to compete with other sources of heat with differing carbon burdens.

The convention allows carbon trading for new power plants whether embedded CHP or new central power plants to compete against existing power plants on the system, without having to guess a future least cost carbon displacement technology and its power production efficiency which is the basis of current conventions and which pre-empts and distorts market force decisions in the heat and power sectors.

The convention also provides a simple and robust basis to evaluate projects and their performance where subsidies or grants are being applied either to the power sector to encourage the use of power cycles that reject heat at a higher temperature by, as an example, by exempting electricity from CHP from climate change levy. It also provides a structure to proved incentives to invest in heat distribution to develop heat loads.

Replacing the central power stations cooling tower heat load with building or industrial heat loads is the only mechanism for achieving any carbon savings utilising the waste heat from power generation. This can only be done by signalling the benefit of developing heat loads to use the waste heat not by signalling lower cost or lower fuel burn electricity the result from a heat as prime product assumption.

4.1 National and International modelling of CHP.

Unfortunately the heat as prime product assumption, identified in this paper as inappropriate has been used for preparation of statistics by the UK, EU and IEA. It has also been used to model CHP in the WASP model and derivatives of WASP for electricity expansion plans by the World Bank and others and is still the basis for regulation in some countries. It is thought to be the basis for the modelling in the recent UK PIU report and the subsequent White Paper on Energy Policy.

It is known that the World Bank has been addressing the issue of modelling CHP correctly but to the authors knowledge the issue can not be handled in current models.

It is thought that the “Orchard convention” and its formula if applied to models will allow simpler and better models to be developed.

4.2 UK Building Regulations part L.

The “Orchard convention” mirrors aspects of the current convention used in Part L of the building regulations. And the use of benchmark power plants. The current convention in Part L correctly follows the electricity as prime product heat as waste product convention but then when negative fuel burns arise for the heat sets these to zero effectively losing a national carbon benefit from CHP operation.

Adoption of the “Orchard convention” in Part L would be simple. The negative element currently discounted in Part L being transferred to reduce the dwellings electrical carbon emissions.

4.3 DTI statistics.

This paper has identified anomalies in the current DTI convention. It is thought that adoption of the “Orchard convention” would allow more correct reporting of statistics and allow the actual carbon benefits for the respective heat and electricity sectors to follow market developments.

Current statistics are calculated against assumptions about future least cost power generation options and efficiencies which may prove to be incorrect and which do not reflect current carbon displacements actually produced by CHP in the respective heat and electricity sectors.

4.4 UK Carbon Trading.

Current CHP carbon trading conventions match the convention for DTI statistics and do not reflect either the current UK market carbon situation or the world market situation. Since coal fired plant or oil fired plant generally reflect the world’s marginal plants and the targets to be achieved are global it would make more sense to evaluate CHP and its fuel against world marginal plant to correctly signal the world carbon benefit from CHP.

Currently little attention has been paid to the heat electricity interface and carbon trading in the heat sector. This interface will have to be regulated as competition based duplicate heat supply networks and electricity networks are not economic.

Adoption of the “Orchard convention” for carbon trading with the regulators determining appropriate benchmarks where actual market benchmark signals fed into the convention are impractical would allow a national and international market to develop with a simple formula for gathering statistics and monitoring the respective sectors.

The proposed "Orchard convention" is thought to resolve many of the problems identified in other conventions and provides a basis for further development for carbon trading and incentives to encourage the use of the waste heat from power generation which in many countries has the potential to heat all the major cities.

4.5 CHPQA

The UK methodology for quality assurance is superior to proposed EU methods which appear to unfortunately be based on an assumption that heat is the prime product from CHP.

The CHPQA methodology is similar in many aspects to the "Orchard convention" with CHP's divided into different "Benchmark" categories according to type of power plant and size.

CHPQA is based on assumptions about efficiencies of boilers displaced to derive the index.

CHPAQA thus is not structured to provide information at the heat electricity interface to develop a market for waste heat in the heat sector.

No reason can be seen why CHPQA can not be adapted using the "Orchard convention" and for it to developed and adopted by the EU as a superior methodology to the methodology currently being considered by the EU based on the inappropriate assumption of heat as prime product.

4.6 Security of supply.

The vulnerability of central power generation and the transmission and distribution system to the weather, terrorist attacks and component failure continues to be demonstrated in London, New York, Baghdad and other part of the world.

Technology now permits control of embedded generation.

In cities such as London there is no reason why every 500 to 750 kVA local transformer could not have a 625 kVA CHP unit near it or in many cases on the roof for the transformer building.

The CHP could be load managed and a multiplicity of local CHP units would provide much better security of supply and availability than a few large central units.

The system would benefit from improve voltage control and reduced costs of reinforcement and transmission vulnerability.

With the current interest in the evaluation of embedded generation and security of supply this option warrants evaluation.

From work carried out in London a 625 KVA CHP providing community heating connected to the LV side of a 500 KVA transformer offers the lowest lifetime cost for reducing carbon emissions for the existing buildings.

4.7 Future action.

This paper and its companion paper are presented with a view to discussing the convention with relevant institutions and government departments with the objective of remodelling UK CHP policy and possible adoption of the “Orchard convention” for UK for Carbon trading purposes, for Part L of the Building Regulations and for UK statistics and for CHPQA.

At the EU and World level adoption of the convention will result in better signals in determining least cost options to meet Kyoto and other carbon targets when evaluating the CHP heat supply option as a means to reduce carbon emissions against heat demand reduction options such as increased insulation and double glazing for the worlds existing building stock where the costs can be substantial between £1800.00 and £3000.00 per kW of heat load displaced.

William Orchard.

September 2003

Note Information on comparative costs of demand side measures and supply side measures using CHP and other issues can be found in the shorter companion paper. “Discussion issues to be considered if CHP is to achieve its carbon saving potential. Proposal for a novel and simple “Orchard convention” for CHP for UK carbon trading.

Acknowledgement:
Max Fette has contributed to this paper acting as a sounding board for the ideas and the joint development of the spreadsheets and charts that illustrate the issues clearly.

5 APPENDIX NOTE ON EFFICIENCY CALCULATIONS AND (HCV) AND (LCV) CONVENTIONS

The HCV convention for efficiency is used in this paper.

Two conventions for the calorific value of fuel are in use, (HCV) and (LCV).

The convention that gives the best signal of how much of the energy in the fuel had been used is an efficiency of conversion based on the gross or higher calorific value of energy in fuel, (GCV) or (HCV).

It is the basis used in the UK for evaluation of the performance of boilers.

The alternative convention (LCV) the lower calorific value of the fuel, does not take into account all the available heat produced in combustion. It assumes that some of the available energy in the fuel can not be used.

The LCV-convention can thus result in conversion efficiencies of over 100%, where products of combustion are condensed.

Presentation of statistics based on LCV results in a higher efficiency of fuel to power conversion being quoted for a boiler or power plant than when the HCV basis is used.

LCV is therefore a convention favoured by power and electricity producers and power plant manufacturers. Typically a CCGT power plant burning gas quoted with an efficiency of 50% on the LCV basis will have an efficiency of 45% on a HCV basis.