MAX FORDHAM

A case against the widespread use of district heating and CHP in the UK

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Executive summary

There is considerable pressure from local and central government that district heating linked to combined heat and power [CHP] or waste incineration should be widely implemented as a solution to reduce our energy and carbon emissions in the UK. This is backed by many members of the engineering community. Max Fordham LLP consulting engineers do not share this view and have conducted a desk study to challenge it. Our concern is that it is a costly intervention that needs to sell heat to be viable and this discourages the adoption of energy saving measures such as insulation and solar heating. Much of the original justification for the carbon savings of the technology was done by comparing burning gas in a CHP unit to the current mixture of fuels that generate grid electricity which includes a large amount of carbon intensive coal. We think this comparison is flawed and that the comparison should be with burning gas on a like for like basis. We have modelled a gas fired CHP and district heating system against a conventional efficient gas fired power station for providing electricity and local efficient gas boilers to provide the heat. We found that, while there are small [up to 17%] theoretical savings available in the CHP system, the heat loss from the pipework and electrical pumping costs inherent in a district heating system and the suboptimal matching of the heat and electricity load to the output of a CHP unit, requiring heat to be stored or dumped, negate any energy advantage in all but the highest density of heat usage.

There are plans to reduce the CO_2 released from electricity generation by using renewables such as wind, tidal or solar, or using carbon capture and sequestration or nuclear energy. When implemented the CO_2 released by the electricity generation from the grid will fall. If reliant on natural gas, the carbon intensity of the electricity from a CHP system will remain as it is now.

Waste and biomass have been cited as “zero carbon “ alternatives to gas and other fossil fuels to be burned locally to fuel the local district heating / CHP system. We argue that while waste is currently an unwanted and expensive burden on local councils it will be soon be seen as a precious resource for many other higher value uses such as aircraft fuel and industrial feed stocks. The amount of biomass in the UK is very limited and the world supply will be a highly valued commodity as it becomes a replacement to fossil fuels. To base a local energy strategy on the inefficient use of waste or biomass may be a costly mistake.

The economic case for generating electricity with CHP is based on allocation of government tax incentives on plant, and avoidance of the levies on the retail cost of electricity by using gas that does not have these additional costs, rather than saving energy or CO_2 emissions. We are concerned that government interventions though regulation, planning, taxation or levies are being used to make an economic case for the strategically flawed application of community energy systems.

We have at one recent example from a housing association who have found that a community heating system is more costly to install and uses more energy than a conventional system that they would put in. Over a 25 year period the additional costs would be £40,000 to £52,000 per dwelling. On the basis that it costs considerably more to install and run and uses more energy, we cannot see any justification for expanding the use of this technology.

The immediate pressure should be to find a way to reduce the heating needs of the building stock by insulation and local solar energy. In the current mix of options continuing to use gas to provide a reducing quantity of heat seems sensible and keeps the clear economic incentive to reduce energy use. To meet the 80% reduction in CO_2 emissions over the next 40 years it may not be allowed to burn fossil fuel gas, and other options such as making gas from biomass or switching to heat pumps driven form a decarbonised grid will be needed. However these subsequent changes and investments will build on the benefits of reduced demand. Continuing to use gas and focusing on insulating buildings would not be creating a stranded asset as a district heating network might be.

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1.0 Preamble

Max Fordham llp is a UK based practice of consulting engineers of about 140 people. Our heritage is designing the services and environmental installations in buildings. We are now involved in the wider context of sustainable development in the built environment including the provision of energy. This has led to an analysis of the wider agenda of energy and resource use in the UK. This paper comes out of discussions held among engineers in the practice who do not think that the proposals for implementing CHP and district heating have had the rigour needed to justify the legislative impetus they have been given. We are publishing this paper in the interests of promoting a debate on the best use of UK's resources. While the data does apply to the UK, the issues will be similar elsewhere. The work was funded by the practice and not by any external body.

Issue 2 of the report elicited responses from the UK based CHPA, Mott Macdonald Fulcrum, Chris Twinn and James Thonger of Arup and David Oliver of Energy Advisory Associates. We have taken on board the comments made to do with the efficiencies of the CHP units and clarified the distinction between the net and gross calorific value of gas clear. On other issues we have extended the commentary to address some of the points raised.

We have added an addendum of a case study. This may or may not represent best practice in the industry but does indicate the issues that are associated with the use of district heating. We would welcome other evidence based case studies that may add to the debate.

2.0 Introduction

A consensus is developing that district heating networks, linked to a central heat source such as a biomass boiler, combined heat and power (CHP) plant or waste incinerator, are a vital part of the UK's strategy to reduce energy consumption and cut carbon emissions.

As a result, there is considerable pressure from the government on developers and local authorities to develop district heating networks and CHP. District heating is the main "allowable solution" mentioned in the DECC consultation on the definition of "zero carbon" development. The main points in the consultation paper are likely to become planning law. In London there is considerable pressure from the LDA [London Development Agency] for new buildings to be enabled to take district heating. The extract of the Mayor's Supplementary Sustainable Planning Guidance below sets out the policy that planners adopt.

> *All developments should incorporate CCHP* [Combined cooling and heating and power] *or CHP wherever feasible. Micro CCHP/CHP can be used within small scale developments, while larger schemes work particularly well as part of mixed-use developments that include residential, which balance heat and power needs through the daily cycle. Opportunities to extend new CCHP or CHP schemes to serve adjoining areas and to link with other schemes should be sought. Energy savings from CHP/CCHP should be included with other energy efficiency savings before renewables are considered.* [24]
>
> And
>
> *Policy 4A.5 Provision of heating and cooling networks:*
> *Boroughs should ensure that all DPDs identify and safeguard existing heating and cooling networks and maximise the opportunities for providing new networks that are supplied by decentralised energy. Boroughs should ensure that all new development is designed to connect to the heating and cooling network. The Mayor will and boroughs should work in partnership to identify and to establish network opportunities, to ensure the delivery of these networks and to maximise the potential for existing developments to connect to them*.[25]

These statements are in amongst encouragement to use solar water heating and passive means to reduce energy consumption. In reality the hierarchy required by the planners to get planning permission is as set out above. As solar heating reduces the economic case for CHP it is not put in. As the planners do not understand and cannot police the passive means of reducing energy consumption, the "Do you have CHP, CCHP, District Heating?" is a very easy question to ask and receive a yes/no answer requiring little interpretation. It is clear that the LDA thinks that CHP/CCHP is better than renewables at saving energy and reducing CO_2 emissions.

There is an undertone that the advent of district heating is a panacea for "hard to heat" buildings, and a reason not to have to reduce their heating demand.

In this paper we analyse the use of district heating and CHP in some detail to challenge these positions. Our analysis concentrates on energy efficiency and carbon savings. It is fair to say that we have found that on paper the argument for CHP and district heating is marginal at best. We have not addressed the economics of the case for or against CHP and district heating in detail. It is clear that it does represent an additional investment over the minimum "business as usual" base case. The business case for the additional investment should be funded by some savings in energy and or running costs. Without saving energy we would presume that it is not possible to make an the economic case with out some distortion of the market.

The structure of this paper is as follows. In Section 3 we outline the broad energy argument. In Section 4 we summarise ancillary arguments. In Section 5 we consider the carbon intensity of grid electricity against which the CHP solution is being judged. In Section 6 we present a sample calculation demonstrating our argument. In Section 7 we consider alternative fuel sources for a district heating system other than natural gas, and Section 8 contains our conclusions. Figures and charts are towards the back of the paper. We have also included a case study which inform the discussion on the actual implementation of CHP and district heating networks.

Our intention is that our analysis should be as transparent as possible. Therefore all the data on which our calculations are based are listed in the Appendix to this paper, for examination and discussion. References throughout the paper are indicated by square brackets [n] *etc*.

2.1 Note on efficiencies

Any discussion about the efficiency of a system needs to use the same basis for the energy content of the raw fuel. There are two available calorific values for natural gas, these are known as net calorific value, or lower heating value and gross calorific value or higher heating value. Gross calorific value is the heat extracted from burning gas if all the products of combustion are brought back to the temperature that the fuel and air were at before combustion including the heat of vapourisation of any of the combustion products, [such as water] brought down below their boiling point. Net heating value is less than gross hating value, the difference being that it does not include the heat of vapourisation of the water vapour produced by the combustion process. Traditionally, engineers from a power generation background quote efficiencies based on net calorific value, whereas boiler efficiencies are usually based on gross calorific value. The reason for this is that condensation of water is problematic in most power producing machinery so the heat of vapourisation is considered unobtainable in power engineering, but less so in boilers. .

In order to be consistent, throughout this report, we have quoted efficiencies based on net calorific value. Note that using the gross calorific value would not have affected the conclusions of this study; the point is simply that it is important to be consistent.

3.0 The energy argument

A district heating system is a network of pipes in the ground that takes heat from a central heat source such as a power station and distributes it around the neighbourhood to provide heating. A CHP unit is a device that makes electricity from burning a fuel and collects the heat rather than disposing of it in the standard way a power station does.

The efficiency of the process of creating electricity from burning fuel is greater in big generators that can get rid of the heat at a low temperature. An advanced combined cycle gas turbine (CCGT) in a modern power station with cooling towers will turn 55 to 60% [1] of the chemical energy from the gas into electricity, as opposed to a CHP unit that will turn 30% to 45% [2] of the gas energy into electricity. This lower efficiency, it is argued, is not a problem because the waste heat from the process can be used locally. To make use of the heat it must be distributed by insulated pipes in the ground to the users who in turn should have a use for it. The distribution system has electrical pumping costs and pipe work heat losses. The heating required for space heating is not constant but seasonal so the heat output from the CHP unit is not always required and some may be wasted. The conventional alternative of an individual gas boiler per dwelling / building has no distribution losses and the heat output will directly match the requirement. New boilers are 90 to 98% [3] efficient. The energy and CO_2 savings are dependant on the magnitude of the system and distribution losses. This is a complex calculation with a number of variables. In Section 6 of the paper there is an analysis that shows that a CHP classed as good quality according to the CHP Quality Assurance standard [22], coupled with district heating, may use more gas and produce more CO_2 than the conventional arrangement of an efficient CCGT power station and efficient boilers.

Large and properly engineered CCGT and steam power stations do have the facility to trade off the amount of electricity produced against the temperature at which the heat is taken from the turbine. This is the case in Malmo, Sweden. To get heat at useful temperatures, the plant will lose about one unit of electricity for every 5 units of heat produced. It is not "free" heat as it comes at a cost of a loss of electricity production. It has been compared to a heat pump in this respect. If a heat pump could produce 5 units of heat for the one unit of electricity it would achieve the same result for the same amount of gas energy in. It is fair to say that a 5:1 ratio from a heat pump is ambitious, but then the losses associated with the control and distribution of the heat from the central CCGT plant will reduce the useful heat available. The relative merits of these approaches is again in the margins of the performance of the technologies.

4.0 The ancillary arguments

Apart from the energy issue there are other considerations when thinking about a district heating and CHP system.

Firstly, while the electricity generated by CHP is quite portable and can be exported anywhere in the grid, ensuring there is a use for it, the heat is not. This may set up perverse incentives to encourage the use of heat. The supplier of the heat does not want the users to reduce their use of heat. That leads on to the view that poorly insulated buildings are not worth insulating and looking for gratuitous uses for the heat. It is an easy and dangerous step to thinking that the heat is "free" which it is certainly not; it has been bought at the cost of less efficient electricity generation.

The fact that there is a need to find a use for the heat generated by CHP (in a fixed ratio to the consumption of electricity) will be a disincentive for the consumer to take advantage of new efficient innovations that may come on to the market over the next 50 years. By way of example, solar thermal hot water heating reduces the demand for heat, and hence reduces the economic viability of the CHP / district heating system. Solar thermal systems have therefore been known to be discouraged in areas with CHP. In this way a true on site renewable energy source is displaced by one that does use gas, or some other form of chemical energy. The lifetime of this decision for any new building is likely to be of the order of 20 – 50 years.

The installation of the district heating / CHP infrastructure is expensive. In itself this is not an issue as a society can spend money on what is thought to be a good idea. However it will need to be paid for and this would quite rationally be done by the energy being sold. The losses in the district heating system are reduced if the density of heat load is high. This means that ideally everyone should be connected to the system. To make the system financially viable and provide enough of a return to form the energy supply companies (ESCOs) to make these investments, the rights of the consumer will need to be compromised such that the ESCO will be a monopoly supplier of power and heat and locks the area into this arrangement. In itself the loss of consumer choice may not be a problem if the benefits are clear. This paper suggests that is not the case.

In an effort to make use of the heat in the summer it has been proposed that the heat be used to drive absorption cooling systems, and district cooling networks. As a starting point an absorption system will use between 0.7 and 1.2 units of heat to get a unit of cooling and a good vapour compression system will use 0.2 to 0.3 units of electricity for the same cooling quantity. The net result is that a similar amount of gas would be required with a local CHP system compared to an efficient chiller powered by a CCGT power plant. A detailed study has not been included in this paper but the same general points discussed above would apply.

Fuel burning power plants in the city will exacerbate the urban heat island if it is done at a large scale. As a rough assessment, to make 1kWh of electricity 3kWh of gas will be burned. If all electricity consumed in cities were generated from CHP, the anthropogenic heat released in the city due to electricity will therefore treble. This is not an insubstantial amount compared to the incident solar radiation.

Air pollution is also an issue. Spark ignition engines can produce NO_x emissions of the order of 1000 to 2000 ppm when operating at their peak efficiency,. In the UK, regulations limit NO_x emissions to 500ppm. In order to meet this target CHP engines operate with a leaner burn which decreases efficiency both in terms of the gross power produced and a reduction of the ratio of electricity to heat produced. In a city environment emissions around 500ppm NO_x are still considered high and many domestic condensing boilers now achieve NO_x emissions of less than 25ppm. This is not to say that all power plants don't have this problem, but if constructed at scale and away from centres of population, it is more economic to scrub the exhaust gases and the effects are less likely to affect people.

Decentralised power generation is cited as a reason for local CHP but the reasons are not clear. When running continuously they will meet a base load for which they will be competing with nuclear and new carbon capture and sequestration [CCS] plants that are part of the planned decarbonisation of the grid. Unless they are brought on at peak times, it will not help the grid meet peaks. Unless they can operate in "island" mode in meeting all the power consumption that they serve, they can't provide backup power in the event of a wider grid failure. The losses in the National Grid are discussed below.

It has been proposed that CHP is a good way to back up wind generation in the summer when the generators can be brought on to make up for the loss of wind power. The corollary of this is that in the winter when the wind is blowing, the CHP would have to back off from producing electricity. The heat needed would then come from boilers, reducing the operation of the CHP unit.

It is possible that all these issues can be addressed with greater levels of engineering sophistication and cost but we need to understand the detail of the engineering application, and how they affect the energy savings and cost to assess if they are worth doing.

4.1 Note on the economics

As an observation, the case for generating electricity at a small scale [ie not a power station] from gas is economically very good. Pay back periods of less than 2 years for a well utilised CHP unit in a hospital are not uncommon making it a much easier way of reducing energy costs than actually reducing usage through energy saving measures. This is due to the fact that gas escapes many of the government levies on electricity [EUETS, Renewables Obligation, CCL, CERT, CESP, FIT, CCS Levy, Carbon Reduction Commitment, Nuclear subsidy?] [26]. In addition the capital cost of CHP plant is subsidised by government with tax relief. The economic advantage is based on the allocation of subsidy rather than energy savings. The advent of the "private wire " networks allows a small scale provider to sell electricity directly to a customer while continuing to avoid the higher levies and the costs of the paying for the national electricity network.
The economic case for district heating is less economically clear. However this could be altered by further government intervention. This report is intended to pre-empt that decision with a debate about the real benefits to society of such an intervention.

5.0 Carbon intensity of the grid

Calculations of the carbon reduction of any initiative are typically carried out using the carbon intensity of the national grid as a reference. Carbon intensity is the amount of CO_2 released for every kWh of electricity produced. Given that the grid is powered by a range of fuel sources and has losses in the electrical distribution, it is reasonable for there to be a generalised figure to allow calculations on an individual building. The current official figure is 0.53 $kgCO_2$/kWh [4] based on the basket of sources that the UK is using. The figure for a coal power station is higher than this and a CCGT power station is lower than this at 0.36 $kgCO_2$/kWh [5]. We can agree that gas is a lower carbon fuel than coal.

When assessing whether district heating / CHP is an appropriate national energy strategy, it would seem logical that the carbon emissions associated with this strategy are compared with those associated with the most efficient form of centralised gas power generation, rather than a basket of fuels that includes coal. In other words, the question should be "is district heating / CHP the most carbon-efficient way of using natural gas?". Unfortunately, the rather less pertinent question that is often posed by those advocating CHP is "is gas-fired CHP more carbon-efficient than burning a mix of fuels including coal?", to which the answer is of course "yes". Irrespective of this discussion about the best use of gas, there is an ambition to "decarbonise" the electricity produced by the grid. This will be via large scale renewable projects such as wind farms, tide, and wave power. Like it or not, it is probable that nuclear energy and carbon capture and sequestration [CCS] from fossil fuel power plant will also play a part in this. To base a calculation for a piece of infrastructure such as CHP and district heating that will last say 50 years on the current carbon intensity reflects a view of the future of power generation that will not change from the current one dominated by coal. This may be true but it is extremely pessimistic and cynical about the government's ability to achieve any change.

Linking a district heating system to a fossil plant that had carbon capture and sequestration or to a nuclear power plant is a source of zero carbon heat at point of use, if one ignores the carbon released in the construction and decommissioning of the power stations and obtaining nuclear fuel. Again it is not free as it comes at a reduction of electricity generation efficiency and incurs the capital costs of distributing the heat. The siting of these facilities, financing and other philosophical and practical issues around this type of technology are not trivial matters. It may be wise to for the facilities to come first before the district heating network is put in place in anticipation of their arrival.

The electrical losses in the distribution contribute to the carbon intensity of the grid electricity. The losses in the grid are published as being 1.5% at HV (the national high voltage network), 1.5% at MV (medium voltage town network) and 4% at LV (the 240/415 volt supply to consumers) [6]. In the analysis below, the CHP system would still be of a sufficient scale to need the MV and LV infrastructure and the associated losses and only save the small amount on the national HV grid.

6.0 Sample calculation

6.1 Very simple calculation

There is much discussion about the optimal manner of sizing a district heating system and a CHP plant, and the losses that are associated with a scheme. We have taken two approaches. Firstly we have taken what we considered the absolutes best case for CHP with no losses in the distribution or wasted heat at all. This is compared to the base case of CCGT and local condensing gas fired boilers. This sets what we think is the outside envelope of the maximum benefits possible from CHP over the alternative and gives a budget for the system losses before exceeding the energy used in the base case. We have kept the numbers rounded and the methodology clear so others can put in alternative numbers should they wish. The ratio of heat to electricity is taken from national averages for housing and the commercial sector. In a dwelling we have assumed that when the heat loss is halved with insulation the total heating goes down to 2/3rds due to the remaining hot water load. In the commercial building the hot water load is insignificant and the total heat is halved if the heat loss is halved with fabric insulation measures.

Existing Housing Stock	**Heat**	**Electricity**	**Total gas used**
Ratio of heat to electricity demand	**3** units of heat	**1** unit of electricity	
Gas used with **CCGT** electricity and individual condensing gas boilers	**3** units of gas (100% efficient boiler)	**2** units of gas (50% efficient CCGT)	**5**
Gas used with **CHP** and a central condensing boiler	**2** units of gas (100% efficient boiler +40% of energy from CHP provides 1 unit of heat)	**2 ½** units of gas (40% efficient CHP)	**4 ½**
Percentage Saving in gas used			**10%**

Insulated existing housing stock	**Heat**	**Electricity**	**Total**
Ratio of heat to electricity demand after 50% reduction in space heating load	**2** units of heat	**1** unit of electricity	
Gas used with **CCGT** electricity and individual condensing gas boilers	**2** units of gas (100% efficient boiler)	**2** units of gas (50% efficient CCGT)	**4**
Gas used with **CHP** and a central condensing boiler	**1** units of gas (100% efficient boiler + +40% of energy from CHP provides 1 unit of heat)	**2 ½** units of gas (40% efficient CHP)	**3 ½**
Percentage Saving in gas used			**12.5%**

Existing Commercial building Stock	**Heat**	**Electricity**	**Total**
Ratio of heat to electricity demand	**1** unit of heat	**1** unit of electricity	
Gas used with **CCGT** electricity and individual condensing gas boilers	**1** unit of gas (100% efficient) boiler	**2** units of gas (50% efficient) CCGT	**3**
Gas used with **CHP** and a central condensing boiler	**0** units of gas (100% efficient boiler + 40% of energy from CHP provides 1 unit of heat)	**2 ½** units of gas (40% efficient CHP)	**2 ½**
Percentage Saving in gas used			**17%**

Insulated Existing Commercial building Stock	**Heat**	Electricity	Total
Ratio of heat to electricity demand after 50% reduction in space heating load	**½** unit of heat	**1** unit of electricity	
Gas used with **CCGT** electricity and individual condensing gas boilers	**½** unit of gas (100% efficient boiler)	**2** units of gas (50% efficient CCGT)	**2 ½**
Gas used with **CHP** and a central condensing boiler	**0** units of gas (40% efficient CHP provides 1 unit of heat; ½ unit of heat is wasted)	**2 ½** units of gas (40% efficient CHP)	**2 ½**
No benefit			**0%**

It can be seen that there is a sweet spot at a heat to electricity ratio that matches the output of the CHP plant. The maximum saving at this point is 17%. As the ratio moves either side of this sweet spot the savings drop off. At ratios of less than 0.5 units of heat to 1 unit of electricity, the poor electrical performance of the CHP will use more gas than the CCGT and gas boiler option. At best a 17% saving is not a big margin to cover the all the harder to quantify down side operational issues and losses from the storage and distribution of the heat.

6.2 More complex model

The second approach takes a view about the distribution losses of a district heating system and assumes that the CHP is sized to meet the electrical load. This is applied to different heat densities. The details of the assumptions are set out below and many experts would disagree with them. We invite any other basis of analysis and suggest that the comparison with the our idealised best case is not so far from the mark.

To assess the performance of a CHP and district heating system we constructed a notional 1km square. The data used in this calculation were taken from published sources, and are listed and referenced in the Appendix to this report. There are many other arrangements that could be modelled. We believe that the assumptions here are reasonable to give an overview of the relative performance of the systems.

6.3 Heat Density

Heat density is a conceptual tool that allows inferences regarding the scale of potential district heating. In this study it is assumed the heat density is directly related to the population density. To calculate this heat density, the population densities for every postcode in the UK were multiplied by the average annual heat demand per person. This heat demand does not include that of the industrial sector since industrial presence is very small in areas of dense population. In any event the model is only looking at the heat density and the only aspect that would change is the ratio of heat to electricity as described in the simple model described in 6.1 above. A national feasibility study of district heating / CHP concluded that a heat density of 3000 kW/km^2 provides good district heating potential [7]. Therefore this was used as the heat density of our notional 1km square for our initial calculations. Higher heat densities were also examined. Approximately 20% of the UK population live in areas with heat densities greater than or equal to 3000 kW/km2.

The heating demand used in our calculation was based on the average annual space-heating requirement for dwellings, and was broken down monthly by multiplying it by the monthly space heating gas demand. In the summer the system met the background hot water load. As such the distribution pipework is assumed to be hot and losing heat through the year. We have assumed that the return water temperatures are not low enough to use more efficient condensing boilers to back up the CHP plant. Lower return temperatures are possible with heating and hot water systems designed to do so but we understand that many of the proposed systems are intended to replace existing boiler heating systems that are designed for higher temperatures. Indeed the heat exchanger between the district heating system and the dwelling means that the temperature of the district heating water needs to be hotter than the water in the dwelling's heating system. This is a small issue but makes the point that it is not possible to get the best output from a gas boiler connected to a district heating system that is in turn connected to an existing building stock

6.4 CHP sizing

We used a very simple method to size our CHP, assuming that electrical and heat demands are constant over a 24h cycle. It has been pointed that this approach is crude, and that it would not be suitable for assessing the economic viability of CHP in a real situation. We contend, however, that basing our calculations on an assumption of constant loads is favourable to CHP, because it maximises the period for which the plant can be operated. If a scenario with constant loads were to occur in practice, it would be considered an ideal case for CHP.

The CHP plant is sized to meet the monthly average electrical demand of the notional community taking into account the losses associated with the local electrical distribution. For the purposes of this simple calculation, there is therefore a perfect match between CHP electrical output and electrical demand for our notional square kilometre. In practice, any surplus electricity would be exported to the grid. The heat is distributed through a network of pipes connecting every building in the designated square kilometre. The length of this network is assumed to be equal to the total length of the street network in the area, plus a short branch to each building. Heat losses from the pipes came from a pipe manufacturer's heat loss calculator [8]. On this basis of sizing, the CHP unit would meet a proportion of the heating in the winter and have a small surplus of heating in the summer, which is wasted (approx 20% of total heat generated). The heat deficit in winter is made up by a central gas-fired boiler.

We assumed that the CHP would run at all times and that the electrical and heating load would be even over the 24 hour period. This idealised approach assumes that the heating system is sized to meet the average load and ignores the peaks in demand. As such the size of the installation is minimised to meet the load and district heating losses are therefore also minimised. Again this is an idealised case and in reality the installation would have to be larger and losses would be higher to cater for peaks in demand.

In our base case we assumed a CHP electrical generation efficiency of 32%, and a usable heat generation efficiency of 53%. These efficiencies mean that the CHP would be classified as good quality according to the CHPQA Standard [22], and is therefore a reasonable approximation of a typical CHP installation. Nonetheless, we are aware that CHP units with higher efficiencies are available. Therefore we also present results for units with higher electrical generation efficiencies, of 37% and 42%.

6.5 Alternative scenarios

We compared the following energy supply scenarios, assuming current UK domestic heat demand:

1. 'current' – electricity supplied by the current UK mix of generation plant, based on a basket of fuels; heat supplied by gas-fired boilers at current UK average boiler efficiency of 72% [9]

2. 'district heating / CHP' – electricity and heat supplied by district heating / CHP, as described above

3. 'CCGT' – electricity supplied by a CCGT power station; heat supplied by efficient condensing gas-fired boilers with an average efficiency of 98% [3] (i.e. all households have installed modern boilers)

We have also run another set of figures assuming that the buildings are insulated to reduce the heat loss by 50%. The justification of the 50% reduction is reasonably arbitrary but not as ambitious as the 80% reduction proscribed by the recent Technology Strategy Board (TSB) funded project to retrofit existing houses.

6.6 Results

The results of our calculations for our base heat density of 3000kW/km^2 are illustrated in Figures 4 - 5. The analysis shows the importance of the carbon intensity of the grid. When compared to the 'current' scenario, which uses a mix of fuels to generate electricity, the CHP / district heating system is shown to be beneficial; the associated carbon emissions for our notional 1km square are approx 8.2 thousand tonnes CO_2 per year with CHP and 10.6 thousand tonnes with current generation plant. However, as we have stated previously in Section 5, this is not an appropriate basis on which to assess CHP / district heating, because in effect it compares burning gas with burning coal.

Using the gas in a CCGT power plant to generate electricity and condensing boilers for heat will use 7.4 thousand tonnes CO_2. i.e. less than the CHP / district heating scenario. So the answer to the question "is district heating / CHP the most carbon-efficient way of using natural gas?" is no. Current best practice gas-fired technologies are more efficient than CHP and district heating.

Reducing the heat loss of the buildings makes the differential even more favourable to the CCGT / local boiler option as the standing loses of the district heating system become a larger proportion of the useful heat distributed.

Figures 6 to 9 show our results for higher heat densities. At a heat density of 10,000kW/km^2, district heating / CHP is still less efficient than CCGT, assuming current heating demand.

As a point of reference figures 12 to 14 illustrate the density of population at the different heat densities. It should be noted that less than 1% of the UK population live in heat densities of over 10,000 kW/km2. Something that might work at this density is not a general national solution.

In figure 10 we have extended the study to compare various heat densities and gas to electric efficiencies. These efficiencies are shown as net and gross percentages for the CHP and central CCGT power plant. We have normalised the data to make the comparisons. The carbon output of the current grid electricity and building heat losses is set at 100 and the relative CO_2 output of the other scenarios are measured against that base. We have included two efficiencies of CCGT being a "normal" operation [52%] and the best possible skid performance [58%] to give a range. For the CHP we have taken 32%, 37% and 42% efficiencies. 42% is really only available to very large installations the size of power stations. 37% is possible in large spark ignition engines but these may not be able to run at the higher efficiencies due to the NOx limitations discussed in sections above. 32% is a relatively safe and achievable efficiency. The effect of increasing the heat density reduces the distribution losses which generates the curves in the CHP results.

Figure 11 is the same data with the heat loss of the building stock reduced by 50% and using condensing gas boilers in conjunction with the central power generation scenarios.

The graphs again show that the biggest saving is in using gas rather than a basket of fuels that includes coal. The relative benefits of a CHP and district heating system over the central generation system using the same fuel are less clear. IN figure 10 the very best CHP [42% efficiency] will have the same performance as a "normal" CCGT at a density of 3000 kW/km^2. The 37% efficient CHP will break even at 6000 kW/km^2 and the 32% efficient one will never do better that the central power generation option. In figure 11, with reduced building heat losses, only the 42% efficient CHP plant does better than the "normal" CCGT, but show no advantage to the best possible [58%] central CCGT option.

The over all conclusion of this is that it may be possible for a CHP/district heating system to save fuel in areas of dense heat loads and very high efficiency CHP units where everything must work at its best. Even then the potential energy savings available are small. However there are plenty of opportunities for less than optimal performance in which the energy use would be higher. On the basis of a limited up side with a potential downside we cannot see how the large investment in the infrastructure would be justified on such small margins and high risks.

7.0 Alternative fuels

So far this analysis has looked at natural gas (methane) as a fuel source. Apart from being a potent greenhouse gas if it is released it is a very clean and useful fuel. As the UK runs out of its own natural gas we could continue to use it and import from Norway, Russia, the Middle East *etc*. However to meet the declared carbon reduction targets the UK will need to cut down on the use of all fossil fuels so alternatives need to be found.

One of the ancillary arguments for district heating is that it facilitates the use of other less-convenient fuels such as waste and biomass in large centralised plant to provide heating to a distributed heat load via the district-heating network

The reduction in fossil fuel use is not just limited to heating and powering buildings but also to driving transport, manufacturing and agriculture. Plant matter or biomass is the only source of renewable hydrocarbons that can be used to replace fossil fuels. Food is also a renewable hydrocarbon. All plants need land to grow and it is clear that this will come into intense competition if we try to replace fossil fuel with bio-fuel. After taking out the inorganic glass and metals that can be recycled from the waste stream, one is left with plastics, paper, food and wood waste of some sort. These all contain some form of hydrocarbon and will release energy when burnt. They also have embedded energy in their manufacture. As such it is better to reuse and recycle them before taking the energy out. They also have the nutrients that can be captured and used to make fertilisers for agriculture, rather than making nitrates from fossil fuel. Perhaps a better use of newly grown biomass is as a replacement of oil for plastics and other materials.

Looking at the quantity of available biomass fuel, the Forestry Commission suggested that there could be 4 million tons of wood available for energy usage. That would only meet 2% of the household heating energy consumption [10]. The Royal Commission for the Environment was more ambitious and suggested that UK could produce 70 million ODT (oven dried tons) of timber that would need 7 million of the 17 million hectares of agricultural holdings [11]. To do this would mean taking some land out of food production. The implications for our national food security mean that this is not a decision that can be made in isolation.

Importing biomass grown overseas is possible as a traded commodity such as food or oil. There have been many studies on the global potential for biomass production. However any study must be set against the other uses of the land for food, biodiversity and the other needs of the country it is grown in. The upbeat IEA report needs to be read with these caveats in mind [23]. It would be better to discount imported biomass energy as a drop in replacement to fossil fuel to heat buildings as there will be so many other more pressing needs for the biomass energy in transport and industry.

The household organic waste stream is about 30 million tonnes a year. This is a considerable resource with a considerable value. This used to go into landfill and the rotting organics produced methane. Captured landfill gas burnt in generators made the largest single contribution [23.8%] to the renewable energy portfolio of the UK in 2009 [12]. The National Grid has published a study [13] stating that for an additional £10bn investment and diverting all the organic waste into anaerobic digestion and gasification plants, they could produce 18% of the total UK gas consumption of 97 billion m^3 a year, or 50% of the annual domestic gas consumption. This could be injected back into the gas grid thus make use of the existing infrastructure. This is not unprecedented and is done in Europe. This has great merit as a strategy for renewable heating of all the gas fired housing stock, provided the heating requirement can be reduced by 50%, which is not an unreasonable target.

British Airways recently announced that it was signing a contract to take 500,000 tons of organic waste to supply 16 million gallons of jet fuel or 2% [14] of its Heathrow aircraft needs. Using all the organic waste would meet all of it. We would argue that this (i.e. using waste / biomass to produce high grade fuel for applications that need it) is a better use of the resource than burning it in an incinerator and making use of some of the heat in a district heating network.

Unfortunately, the organic waste of the UK is being dealt with by local authorities on a piecemeal basis. The land fill directive is forcing the pace to stop using land fill and is obliging them to find another solution. This tends to be a short term fix that leads to long contracts with companies to pay to take the waste away dispose of it as cheaply as possible within the law. Any potential benefits from the waste will be locked away for the period of that contract. Making use of the heat from the incineration via a district heating network has proved to be very difficult to afford.

Hydrogen is a fashionable fuel that is not naturally occurring. In a fuel cell it will produce electricity as efficiently as a CCGT and provides high grade heat and pure water with little pollution. The fuel cell is scaleable and is being looked at for cars and busses to reduce pollution in dense urban environments. Storing the smallest molecule in the universe has its problems. It can be made from the electrolysis of water from electricity, in which case it functions as a battery. Alternatively it can be made from a hydrocarbon such as oil, natural gas, or organic waste in a process that takes the carbon and some of the energy value out of the raw fuel to make clean hydrogen. The CO_2 is then released or can be injected into the ground or into some other industrial usage such as a greenhouse. This infrastructure is not in place. A CHP unit in a district heating scheme could be replaced with a fuel cell in time. However the same arguments about the losses would apply and it is likely that small household units will be available as replacements for gas boilers to give the benefits directly to the consumer using gas.

We are not saying that the answer to providing energy for heating buildings is straight forward, but it needs to be addressed in the wider national context of how we are using our fossil and renewable energy resources.

8.0 Conclusion

Our analysis suggests that the current best practice of individual condensing gas boilers and CCGT central power generation is a comparable in efficiency and in most cases better than using gas in a CHP / district heating system. Furthermore the current practice allows the market to develop low energy and local renewable solutions as they arise on a piecemeal basis in the future. We believe that it is wrong to alight on district heating linked to CHP, biomass or waste incineration as a panacea for heating buildings in the UK, and it is an unhelpful step to lowering our reliance on carbon emitting fuels. Rather than a benefit to the community there is a risk that it is an expensive stranded asset that the community will have to keep paying for. The limited sample of district heating network installations we know of have been more costly to install and used more energy than the conventional alternative. We have not seen an evidence base that counters this but would welcome it.

The economic case for CHP is driven by a particular set of subsidies that favours this method of burning gas to produce electricity, and not because of saving fuel. This policy in itself is a poor use of society's money. The broad conclusion of this paper is that there is not an energy argument for constructing a community heating system and there is not sufficient subsidy to make an economic case for it either. The concern is that the current interventions in the planning system and further ones such as in the definition of "zero carbon" will make the installation of these networks an imperative.

Any investment of this sort should endeavour to look forward to see how the asset might fit into a national energy strategy over the next 20 to 50 years. It would be sensible to base a personal view of this future on the current global state of play. This is in the absence of a published national strategy and the fact that the government may change its mind in as competing pressures drive policy in one way or another.

Large investment is required to reduce the heat loss in buildings and to "de-carbonise" the electricity supply. The money we have to spend should be focussed on these goals rather than district heating networks. In the current mix of options continuing to use gas to provide a reducing quantity of heat seems sensible and keeps the clear economic incentive to reduce energy use. In time there may be sources of heat from "decarbonised" power stations that may make a district heating network viable. However it is not as yet clear if that is the direction the UK will go in or if that is better than using the decarbonised electricity to drive a heat pump.

In our view the urgency is to find the best ways of making use of biomass and waste that does benefit the community. It has a real value that needs to be fully understood and realised. Burning it simply to heat buildings does not make full use of the resource to make products, fertilisers and transport fuel. It could be used to make gas to displace fossil fuel gas and make use of the existing gas infrastructure. The combustion of biomass combined with carbon capture and sequestration provides the opportunity to use plants to remove CO_2 from the air, and the power station to put it into the ground. As with most industrial processes this is most efficiently done at a large scale and at appropriate sites.

What land is used for [growing food, energy, amenity, biodiversity and construction] is in itself a national strategic issue.

These are the areas in need of clear coordinated national policies to encourage the large-scale industrialised investment required to make a transition to a secure, economic and low carbon emitting future.

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Appendix – Case study of Hyde housing:

In our desk study we concluded that district heating and CHP might offer marginal benefits in certain circumstances provided that everything worked well and was optimised. The case study below shows that the reality is a long way from this situation. The experience was that there are no benefits to the installation, only additional costs. We would not like to suggest that this is the only way of utilising it but illustrates the difficulties of making a marginal technology work in the real world. Before moving on with this technology we would like to see a good evidence based analysis about how it would work in practice and that deals with the theoretical and practical issues that have been identified.

Report form Hyde housing:
Hyde Housing Association has installed and operated community heating systems over the period 2007 to date. They have over 600 dwellings with community heating with another 1500 planned. In a confidential report produced for the GLA in July 2010, they have reviewed the cost and performance of their systems in comparison to more conventional systems. The conclusions on the costs are:

- *Extra-over capital costs being charged are £7,000-£10,000 per flat*
- *Extra-over maintenance costs are £80 per flat per annum*
- *Extra-over replacement costs are £290 per flat per annum*
- *Extra-over administrative costs (standing charge) are £108 per flat per annum.*

> *…………On this basis the best case total extra-over cost of decentralised heating over 25 years compared with conventional heat supplies amounts to around £40,000 per unit (28,161 + £11,950). Worst case (using the capital cost of £10,000) is £52,000 per unit over 25 years.*

As part of their conclusions:

> *"Under current arrangements, decentralised heating systems not only add very significantly to energy costs, but fail in their primary purpose of reducing carbon dioxide emissions. We therefore do not think that further decentralised energy systems should be promoted or required until these issues have been better resolved."*

Appendix – Assumptions / basis of calculations

Assumptions 0 – common to all scenarios

Ref	Parameter	Value / assumption	Notes	Reference
0.1	Annual energy use per person (due to both domestic and commercial buildings i.e. home and work)	8700 kWh/person annual average heating 2997 kWh/person annual average electricity	We used values for domestic and service buildings only, ignoring industrial, on the basis that there is not much industry in areas of dense population.	[15], Table 1.14
0.2	Population density of typical community	3020 people / km^2	Population density that corresponds to a heat density of $3000kW/km^2$	[7]
0.3	Size of typical community	1 km^2	Notional area	
0.4	Number of households in typical community	1258 households	Based on UK average household size of 2.4 people.	[16]
0.5	Length of public roads in typical community	15 km	Landuse data gives a percentage land use for each UK postcode. An average of 10 selected areas of similar heat densities were chosen. Assuming average road width of 9m, and dividing the total road area gives an estimated road length for the area.	[17]
0.6	Efficiency of existing boiler plant	72 %	UK average boiler efficiency as installed	[9]
0.7	Heat losses from typical household	7.8 MWh / annum 4.3 kWpeak	DUKES quotes UK domestic gas use is approximately 350TWh/year. The UK has approx 26Million households, therefore they use 13.5MWh/year each on average. This corresponds to 10.3MWh heat delivered at a boiler efficiency of 77%. From water usage info estimate 3kWh/peron.day for water heating. This is 2.5MWh/year for water heating. Therefore 7.8mWh/year for heating. Peak value assumes that there are 1900 degree days for typical dwelling, therefore 170W/K heat loss.	[18] and [19]
0.8	CO_2 emissions from burning gas	0.206kgCO_2 / kWh	Based on the net calorific value of natural gas.	[20]

Assumptions 1 – existing building stock and energy sources

Ref	Parameter	Value / assumption	Notes	Reference
1.1	Current CO_2 emissions associated with grid electricity	0.530kgCO_2 / kWh		[20]

Assumptions 2 – CHP

Ref	Parameter	Value / assumption	Notes	Reference
2.1	CHP type	Gas Engine	Standard CHP technology.	
2.2	CHP operation strategy	CHP operated year-round to meet average electrical demand	CHP has been sized to meet the electricity demand of the population. A central backup boiler is to engage when CHP heat supply becomes insufficient.	
2.3	What happens to surplus heat?	Rejected to atmosphere		
2.4	How is heat deficit made up?	Central Condensing Gas Boiler	Efficiency of 98%. Assuming the return temperature of the hot water is low enough, a condensing boiler is used.	
2.5	CHP electricity generation per kWh gas burnt	0.32 kWh	Based on manufacturer's data for a typical unit	[2]
2.6	CHP electrical distribution losses	5.5%	This is the energy lost in MV and LV distribution	[6]
2.7	CHP usable heat generation per kWh gas burnt	0.53 kWh		[2]
2.8	Heat distribution losses	15 kW / km of pipe	Based on manufacturer's data for a typical pipe	[8]
2.9	Length of heat distribution pipework in typical community	22.0 km	Road length + 5m per dwelling.	

Assumptions 3 – CCGT plus efficient boilers

Ref	Parameter	Value / assumption	Notes	Reference
3.1	Electrical generation efficiency of CCGT plant	58 %		[1]
3.2	Grid electrical distribution losses	7 %	Losses from power station to LV customer	[6]
3.3	Efficiency of replacement boilers	98 %	Typical for new condensing boiler	[3]

Figure 1 - Mixed Source Grid Electricity and Local Gas Boilers – Current Housing Stock

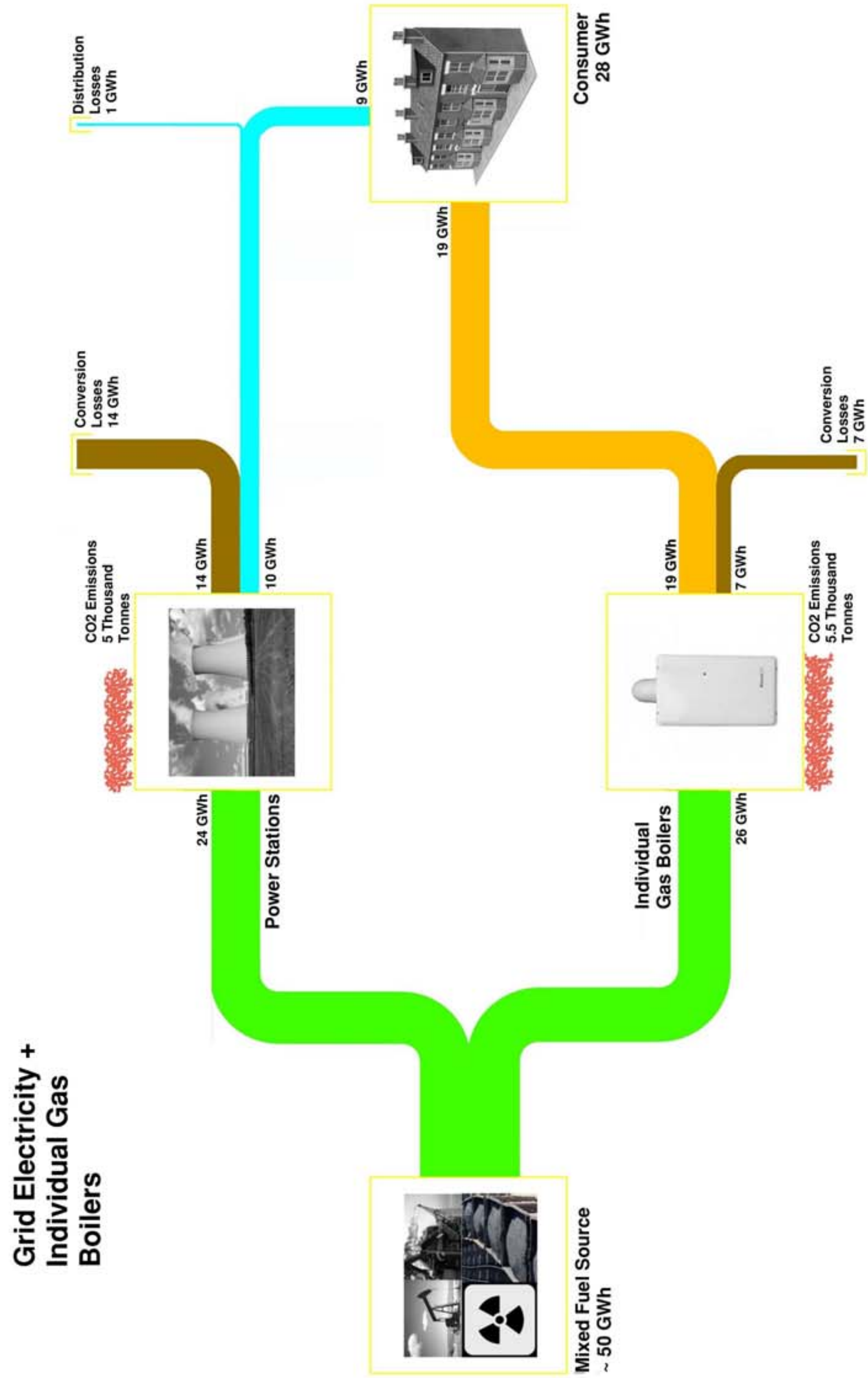


Figure 2 - CHP Electricity and Heating with Central Backup Gas Boiler – Current Housing Stock

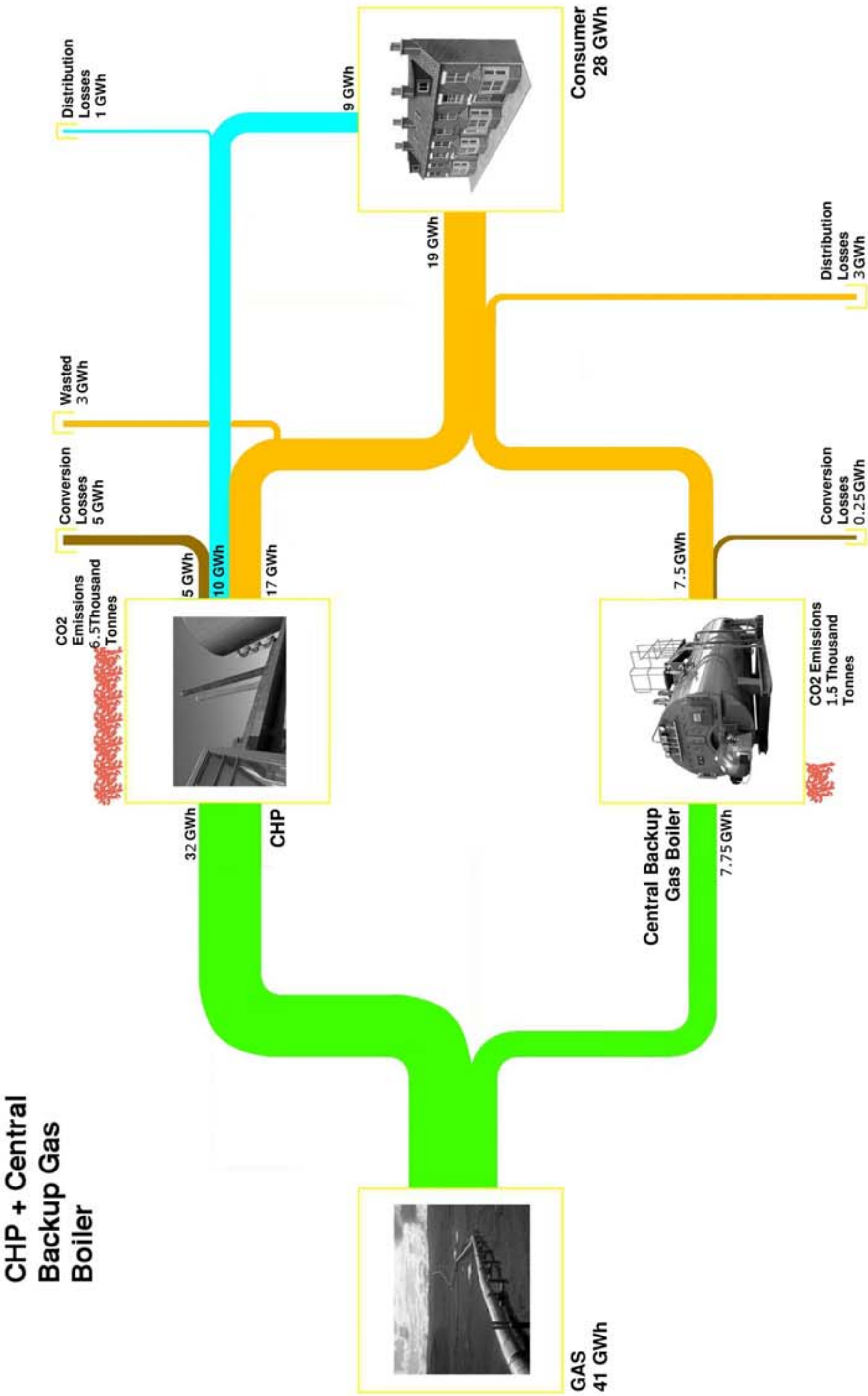


Figure 3 - CCGT Grid Electricity and Local Condensing Gas Boilers – Current Housing Stock

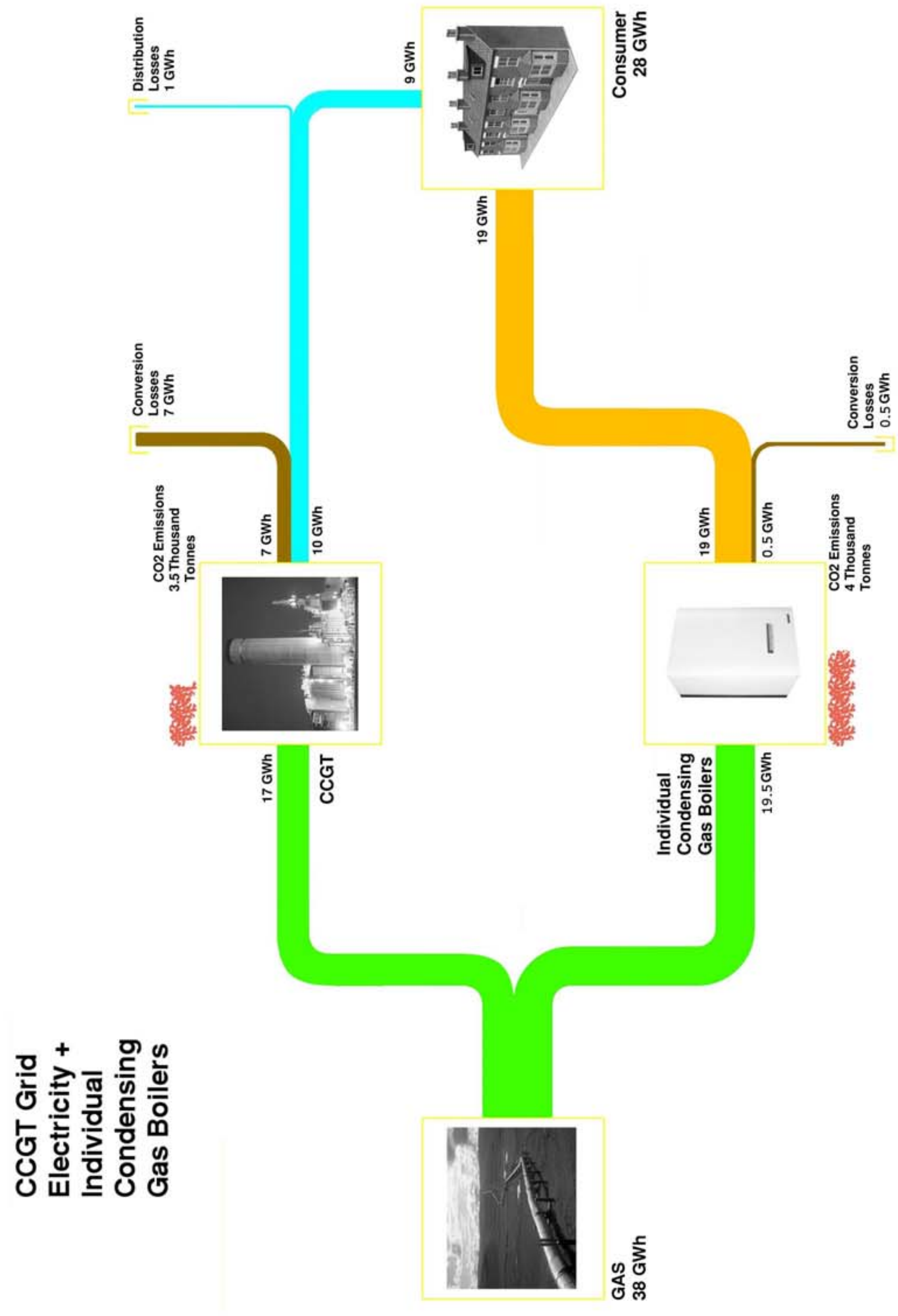
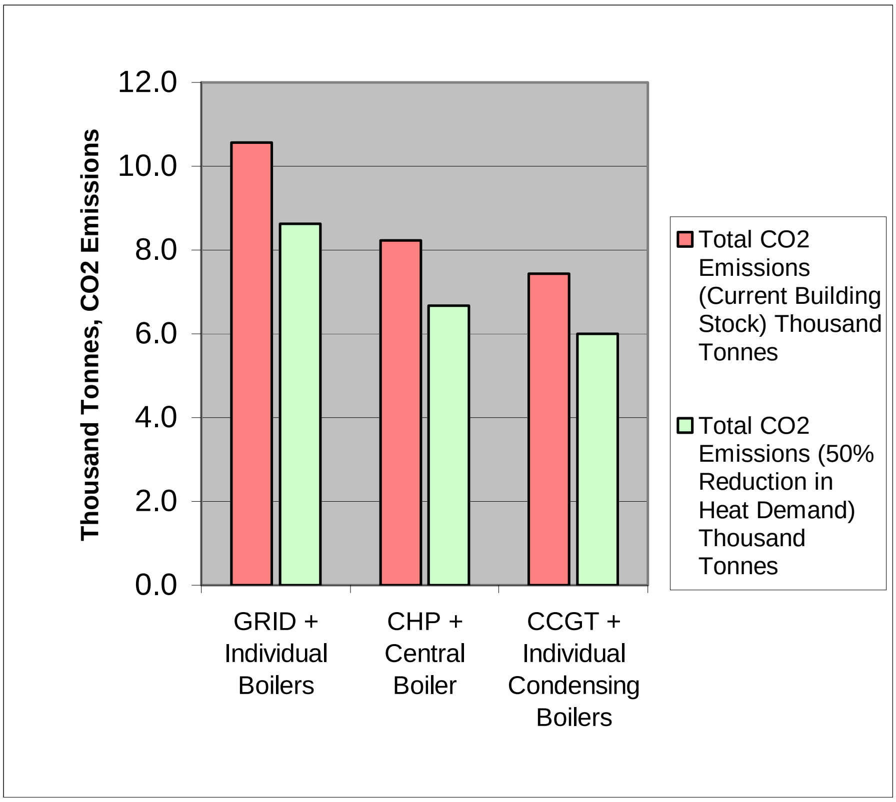


Figure 4 - CO_2 Emissions at Heat Density of 3000 kW/km^2



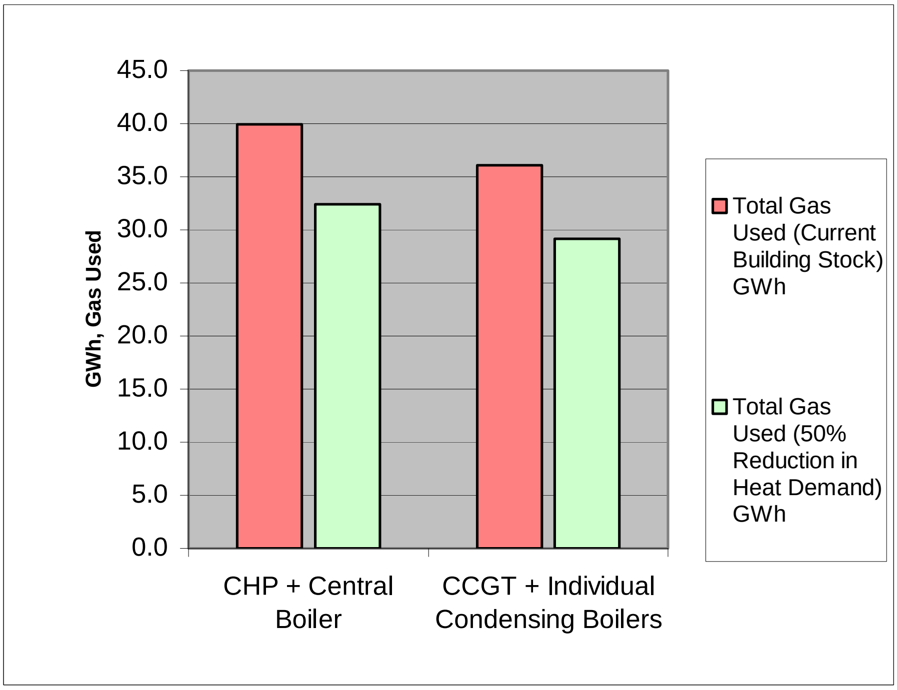
Notes:

CHP – Plant sized to meet averaged daily electrical demand over 24 hours.

- A central backup gas boiler for heat deficit.

- Excess summer heat is wasted.

Figure 5 - Gas Used at Heat Density of 3000 kW/km^2



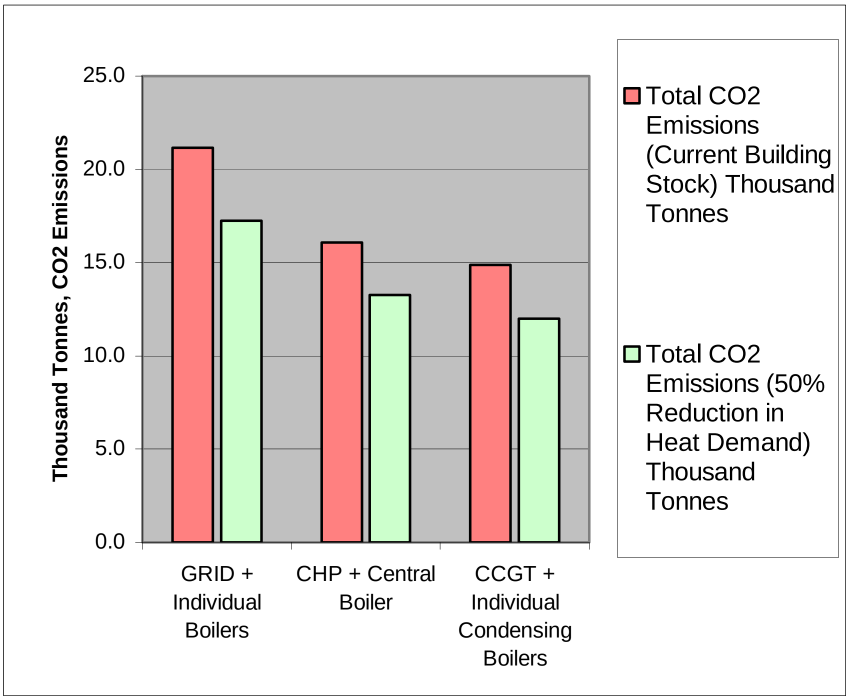
Notes:

CHP – Plant sized to meet averaged daily electrical demand over 24 hours.

- A central backup gas boiler for heat deficit.

- Excess summer heat is wasted.

Figure 6 - CO_2 Emissions at Heat Density of 6000 kW/km^2



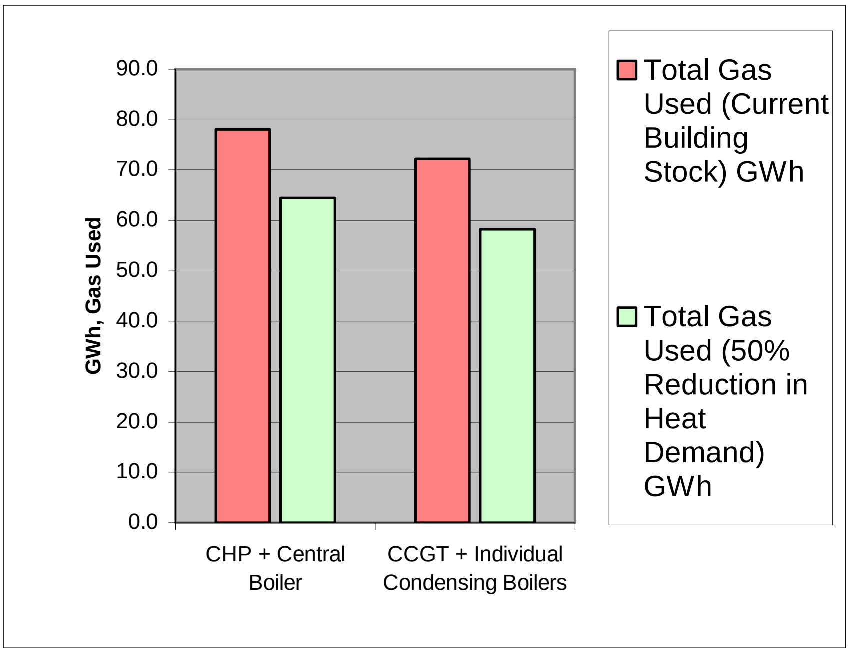
Notes:

CHP – Plant sized to meet averaged daily electrical demand over 24 hours.

- A central backup gas boiler for heat deficit.

- Excess summer heat is wasted.

Figure 7 - Gas Used at Heat Density of 6000 kW/km^2



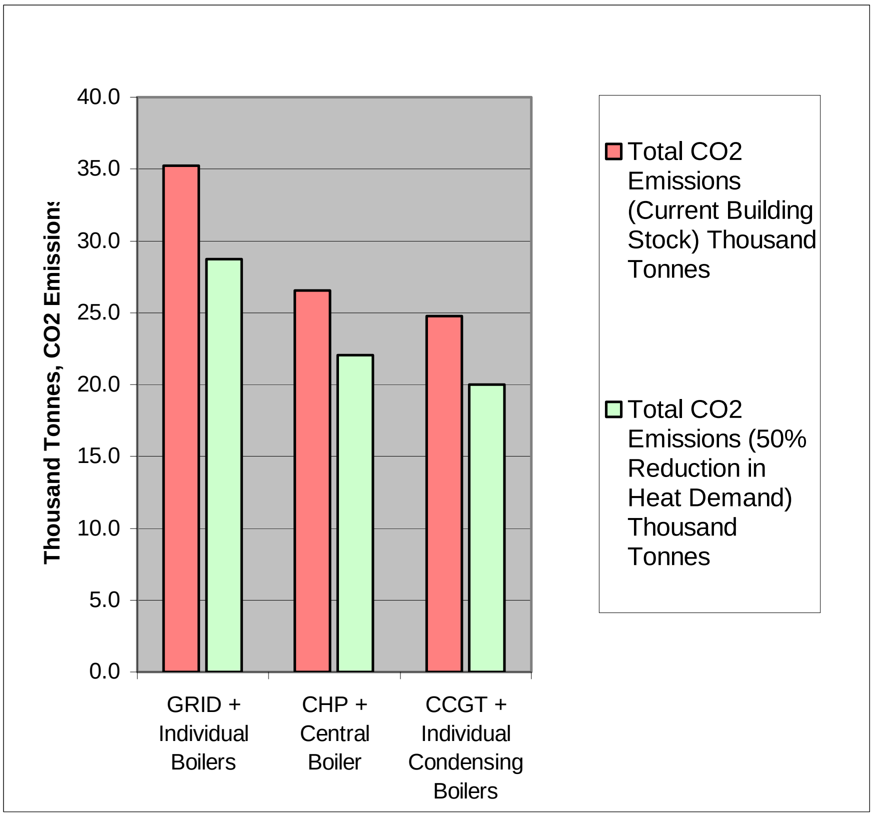
Notes:

CHP – Plant sized to meet averaged daily electrical demand over 24 hours.

- A central backup gas boiler for heat deficit.

- Excess summer heat is wasted.

Figure 8 - CO_2 Emissions at Heat Density of 10000 kW/km^2

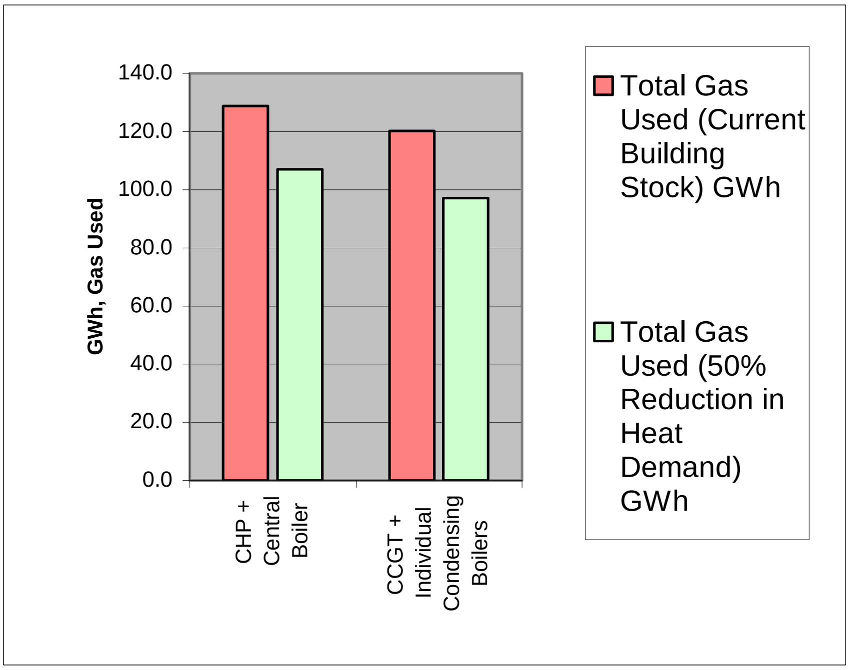


Notes:

CHP – Plant sized to meet averaged daily electrical demand over 24 hours.

- A central backup gas boiler for heat deficit.
- Excess summer heat is wasted.

Figure 9 - Gas Used at Heat Density of 10000 kW/km^2



Notes:

CHP – Plant sized to meet averaged daily electrical demand over 24 hours.

- A central backup gas boiler for heat deficit.
- Excess summer heat is wasted.

Figure 10 – CO_2 Emissions, Current Housing Stock

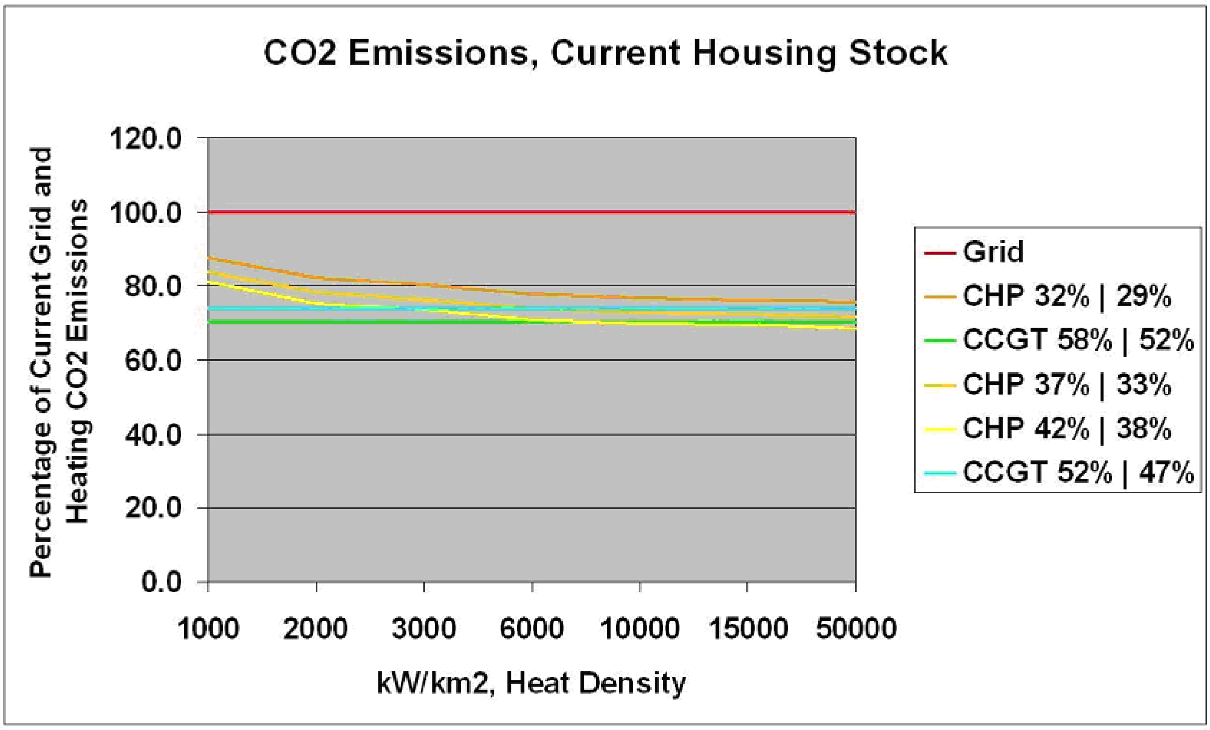


Figure 11 – CO_2 Emissions, 50% Reduction in Heat Demand

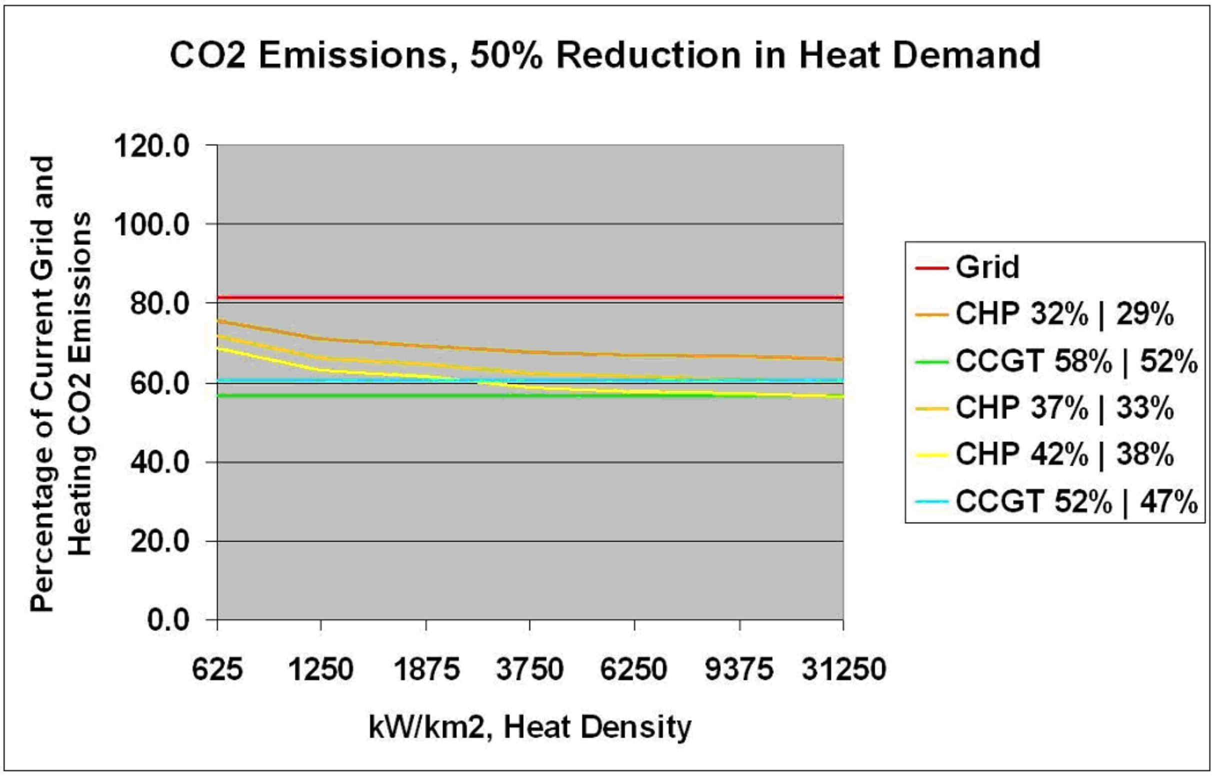


Figure 12 - Typical Urban Population with a Heat Density of 3000 kW/km^2 (Enfield, Middlesex)

20% UK Population living in areas of heat density greater than 3000 kW/km^2

Figure 13 - Typical Urban Population with a Heat Density of 6000 kW/km^2 (Wandsworth, Greater London)

4% UK Population living in areas of heat density greater than 6000 kW/km^2

Figure 14 - Typical Urban Population with a Heat Density of 10,000 kW/km^2 (Earls Court, Greater London)

Less than 1% UK Population living in areas of heat density greater than 10,000 kW/km^2