Criteria and Heat Measures for Carbon Saving **Gordon Taylor** **2008-04-02**

Summary

As noted in the Stern Review and elsewhere, both climate and energy require prompt action. The end-point for all planning, including climate and energy planning, must now be sustainability. This requires a complete energy transition, with a 100% reduction in carbon emissions. Regarding heat, such a reduction could be approached by new building or refurbishing existing buildings to the Passive House standard or switching to biomass heating. However, our towns, cities and heritage buildings cannot be completely rebuilt or even refurbished, and home-grown biomass would be insufficient, so other measures must be considered for the majority of existing buildings.

When choosing energy supply measures, scale and system effects are very important. Units with outputs 1000 to 100,000 times larger have much higher performance and much lower cost, along with higher reliability. On-site measures are intrinsically small, whereas large units are off-site and require networks to aggregate the loads. However networks experience diversity of demand, making it only about half the aggregate. As for system effects, networks also accommodate variability, and increase reliability, yet with high load factors on all expensive plant.

Energy losses are minimised by 'exergy matching', so the ideal carrier for space and water heating is piped hot/warm water. This can be supplied as District Heating (DH) from Combined Heat and Power (CHP) plants. By considering the thermodynamics of such plants and only the fuel used for heat, the savings in fuel use and carbon emissions are shown to be around 80%. Based on meeting 80% of the residential, 100% of the commercial/public sector and half of the industrial heat load in 2020 with DH, with a carbon saving rate for CHP of about 80%, the potential carbon saving is 121 $MtCO_2/y$. Also District Cooling offers carbon savings of 85% or more. Moreover, the DH-CHP infrastructure could use industrial reject heat, municipal waste, biomass, solar heat and geothermal heat to increase the fossil fuel and carbon saving rate to 100% and the potential carbon saving to 154 $MtCO_2/y$. Buildings beyond the heat networks could use Passive House standards and biomass heating, with a potential carbon saving of 19 $MtCO_2/y$. Higher temperature industrial process heat could come from biogas and renewable electricity – so saving the remaining 47 $MtCO_2/y$. For heating and cooling these measures best offer the carbon savings of 100% needed for sustainability.

The cost of DH-CHP may be substantially offset by savings in fresh water supplies of some 44% and from the simultaneous installation of broadband cables. With fuel and carbon savings of 80 to 100% and a 'build-up' time of only seven years, the potential magnitude and speed of savings with DH-CHP etc. could exceed those of any other measure. No other measures could achieve such carbon savings rates with our existing towns, cities and heritage buildings. Significantly, it is already used increasingly in over 1000 cities on the Continent. Thus it would also be essential for meeting the UK climate and energy objectives, including sustainability.

The only purpose of Government evaluating the various measures for fuel and carbon saving is to determine whether and what solutions exist for the committed targets and sustainability. In view of their importance for UK climate and energy policy, these findings should be confirmed by much more extensive studies. Such work should be carried out by at least three consulting engineering firms, with at least two from the Continent, who are already knowledgeable in the field and have all the evidence at hand.

With the knowledge that sustainable solutions were available, Government would then be able to invite Energy Service Companies (ESCOs) to take up franchises for all the UK energy markets, subject to absolute Carbon Emission Obligations (CEOs). These would be based on market shares of the national carbon emission milestones on the road to sustainability.

The CEOs must be delivered by energy savings and supply measures, and only within the UK. Measures under Joint Implementation and the Clean Development Mechanism would not address the policy objectives of security of energy service and the elimination of fuel poverty within the UK. However, trading of carbon credits or certificates could be permitted at the margin – to reward over-performance and penalize under-performance.

With Government having set the appropriate framework, delivery of the lower carbon emissions should be left to the ESCOs and their professional engineers. They have access to the necessary low-cost, long term funds and the knowledge and skills – and the incentive - to determine and implement the 'best' carbon saving measures on time.

Introduction

The Stern Review pointed out the urgent need to reduce GHG emissions to achieve atmospheric stabilisation. (Ref. Stern N., 2006, 'The Economics of Climate Change'. Executive Summary, Fig. 3. http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/sternreview_index.cfm). Although a recent Government document was entitled 'Planning for a Sustainable Future', sustainability is barely mentioned in the Heat Call for Evidence document. Also, it omits many of the criteria relevant to choosing between the options or measures, particularly for sustainability.

In the area of energy and buildings, local and national government in the UK has produced a whole series of 'initiatives', including the 'Merton Rule' and 'Zero Carbon' proposals. These have prescribed certain measures, yet are lacking in supporting evidence, especially of achieving sustainability. When defining policy, only the performance should be specified – here reduced carbon emissions. Prescribing measures constrains the solution, which is then likely to be less effective or cost-effective. Moreover, there is evidence on various measures available from analyses and field trials, both in the UK and on the Continent. This shows that all of the on-site renewable measures – except biomass heating - prescribed by the proposals are either ineffective or far from cost-effective. Therefore mandating these before considering the evidence would result in the declared object of policy being more expensive or even missed entirely. Furthermore, whenever such prescribed measures were less effective or cost-effective, they could never form the basis of viable new companies and industries. Only products that fulfil the science-based criteria would find any sustained market, whether at home or overseas. Those that do not would fail, yet still incur opportunity costs. (Ref. In Picenum, 2007, 'End of Domestic-scale CHP'. http://inpicenum.com/2007/02/27/end-of-domestic-scale-chp/).

Science and technology is worldwide. Also, the climate and energy challenges are the same worldwide, with some differences in energy use due to climatic region and state of development. However, they can still be considered as heat and electricity services and transport. Therefore we should be very suspicious of solutions that are unique to the UK. There are other countries in similar climatic regions and a similar state of development, notably on the Continent. We should assume that their solutions are not stupid but valid, and that we could learn from them.

What is needed is a single science-based plan, going all the way to sustainability, such as those evidently adopted by at least NL, CH, DK, SE and DE. Hence this response includes the criteria that should be considered for sustainability, with some relevant evidence, and suggests a methodology for finding solutions and a framework for delivering them. It is based on my earlier documents. (Ref. Taylor G., 2002, 'Energy Solutions for 60% Carbon Reduction', http://www.energypolicy.co.uk/epolicy.htm and Taylor G., 2007, 'Energy Criteria for Sustainable Energy Solutions', http://www.energypolicy.co.uk/Gordon_Taylor8e.pdf).

Sustainability

The Policy Drivers

Climate change mitigation is urgent and requires a transition to sustainability. (Ref. Stern N., 2006, 'The Economics of Climate Change'. Executive Summary, Fig. 3. http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/sternreview_index.cfm and Spratt D. et al, 2008, 'Climate Code Red'. http://www.carbonequity.info/download.php?id=6). Indeed, to avoid serious climate change impacts, the GHG concentration will probably have to be reduced below present levels. (Ref. Hansen J., 2008, 'Global Warming: The Perfect Storm', http://www.columbia.edu/~jeh1/RoyalCollPhyscns_Jan08.pdf). Moreover, climate change or the inability to pay for fossil fuels may necessitate an acceleration of fuel and carbon saving and the inevitable energy transition at any time. For example, a 'Chernobyl-plus' event at any of the world's 400-odd ageing nuclear reactors would lead to calls for rapid shut-downs, and further demands on declining fossil fuel supplies. Yet according to a recent assessment, the coal resources are far smaller than previously thought. (Ref. Energy Watch Group, 2007. 'Coal: Resources and Future Production'. http://www.energywatchgroup.org/fileadmin/global/pdf/EWG_Report_Coal_10-07-2007ms.pdf). The climate and fossil fuel constraints may be compared. (Ref. Taylor G., 2007, 'Energy Criteria for Sustainable Energy Solutions', Slides 7 – 12, http://www.energypolicy.co.uk/Gordon_Taylor8e.pdf).

Strategic Context

As the world production of oil, gas, coal and uranium peaks, the prices must rise continuously. Moreover, this will occur while – on present policies – UK imports would continue to increase. With the oil price passing $ 100/barrel and the world facing recession, Governments should stop planning for unlimited growth. Already some countries – including NL, CH, DK, SE and DE - are planning and implementing their transitions to sustainability. For example, the Netherlands Government had a Sustainable Technology Development project that ran for five years. This was aimed at achieving Factor 10 – 50 reductions in the use of metals, fossil fuels and carbon emissions and continues with a dissemination phase. (Ref. Weaver P. et al, 2000, 'Sustainable Technology Development', ISBN 1-874719-09-8). Furthermore, Sweden intends to become 'Off Oil (dependence) by 2020'. (Ref. Guardian, 2006. 'Sweden plans to be first world's first oil-free economy'. http://www.guardian.co.uk/environment/2006/feb/08/frontpagenews.oilandpetrol). Also they are implementing appropriate measures. These are based largely on their huge forest industries, which already produce pulp and paper. They are now producing increasing amounts of biomass (wood fuels) and will soon be producing biofuels (cellulosic ethanol). Both Swedish and international makers are producing suitable vehicles for the Swedish market.

Depletable fuels are all 'zero sum' resources - the more for us, the less for them - where most renewables are not. The UK would have fewer enemies if it were no longer competing in the 'zero-sum' game for the declining resources of fossil and nuclear fuels. This would in turn require far lower expenditures of money, energy, lives and limbs on military forces for fighting resource wars. These are already a huge burden on the economy and society. Military spending by the USA is over $ 150 bn/y, much of it oil-related. Relative to oil imports of 11 mbpd, this is $ 37 per barrel, roughly $ 1 per gallon. (Ref. Klare M., 2004. 'Blood and Oil', pp 62, 182. ISBN 978-0-14-102003-7). Each UK person killed represents the loss of an investment of over a quarter of a million pounds in education and training. Each person injured or incapacitated could cost the UK even more for the rest of their lives. This was evidently recognised long ago in those countries which are planning and implementing their transitions to a sustainable energy future – none of which have large military forces. Since, like them, the UK cannot hope to win resource wars against the USA, Russia, China or India, a rapid transition to sustainability is not just prudent, but the only viable policy.

Backcasting

To meet the climate and energy challenges, it is necessary to plan all the way to the end state, where in a finite planet, the only viable end state is sustainability. If any lesser objective was adopted, there would be no certainty of being able to make a later transition to sustainability. This is best assessed by 'backcasting', as pioneered - at least in this context - by Mulder and Biesiot. (Ref. Mulder, H.A.J. and Biesiot, W. 1998, 'Transition to a Sustainable Society', ISBN 978 1 85898 731 6). The resulting insight is that the remaining resources of fossil fuels must not all be spent on current consumption but a significant part invested in the infrastructure for sustainable energy services. An energy transition of some sort is inevitable, but the sooner we start, and the more we invest in such infrastructure, the higher the level of sustainable energy services. (Ref. Taylor G., 2007. 'Energy Criteria for Sustainable Energy Solutions', Slides 3 and 4. http://www.energypolicy.co.uk/Gordon_Taylor8e.pdf).

Criteria for Sustainability

Accounting Units

Energy services can be provided by savings as well as supply measures. Hence, it is absolutely wrong to compare only energy supply measures on the basis of the cost of final energy - e.g. pence per kWh of electricity. These are invariably based on so-called 'levelised' costs, which assumes that today's fuel costs will prevail for the whole life of the plant - e.g. 20 to 50 years. This cannot be true for any using depletable fuels, particularly after world production has peaked. Also, these costs invariably exclude many 'external' costs - of pollution etc. - and subsidies, both open and hidden. Therefore, the money values of objects are artefacts, only loosely related to the energy expended in creating them. Furthermore, we are now in the end-game, with the issue being survival of life on this planet. Therefore, as in war, the money cost – at least in comparison with today's energy costs - is irrelevant. However, the energy and carbon costs of all our future investments are more important than ever. These costs, especially for our energy-related investments, will directly affect the level of sustained energy services after the transition.

EROI

For energy saving and supply measures, the value-for-energy is measured by the ratio Energy Return on the (Energy) Investment (EROI). This is the Lifetime over the Energy Payback Time (EPT). Determination of the EPTs and hence the EROIs of all the proposed measures requires Life Cycle Analyses. Therefore the energy saving and renewable supply measures adopted should have high EROIs. This criterion will increase in importance as low-cost fossil fuels are depleted and energy must be invested in infrastructure for sustainable energy services. It will be particularly important for countries like the UK which are already net importers of fossil - and for that matter, nuclear - fuels. However, for energy saving and renewable supply measures, especially those with only small operating costs, where the EROI is not known, the money cost of carbon saving is a suitable (but inverse) proxy, so can be used to rank order them.

Energy Services

To meet the demands across the whole energy economy - heat and electricity services and transport - the only sustainable energy options are energy savings and renewable supply measures. Compared to fossil energy, all renewable energies are relatively diffuse, and therefore more expensive to harness. However, we require not energy as such but energy services. Thus savings are at least as good as supply. Indeed, they are actually better because they increase security of not supply but service, with little or no subsequent outlay. Hence energy savings measures will be more effective and cost/energy-effective up to a 'Point of Diminishing Returns'. (Ref. Feist W., No Date, 'Passive Houses from Pilot to Mainstream in Germany', http://malmo.se/download/18.1f60430104c0456fc68000698/Feist.ppt, Slide 23). Indeed in the buildings sector, many carbon saving measures have negative lifecycle costs. (Ref. Vattenfall with McKinsey, 2007, 'Global Mapping of Greenhouse Gas Abatement Opportunities', Slide 44. http://www.vattenfall.com/www/ccc/ccc/Gemeinsame_Inhalte/DOCUMENT/567263vattenfall/P0271632.pdf). However, even these values are conservative, due to the use of 'levelised' costs for the fuel saved.

Renewable energies from water, wind, sun, field and forest are indigenous, and thus inherently secure – save for imported biomass/biofuels. However, even these are available year after year, and from multiple suppliers, not limited to the 30-odd declining oil and gas provinces. Hence at any given time, supplies of biomass/biofuels should be available from areas not subject to repressive regimes and conflicts. Moreover, since logs, wood pellets and liquid biofuels all have fairly high energy densities, they are both storable and shippable. The only reservation is that the supplies are limited by land area and rainfall etc. and early adopters may enter into long-term contracts, so that late-comers like the UK may have difficulty in arranging supplies. Biomass is the only 'zero-sum' renewable.

For an idea of the respective contributions of energy saving and renewable supply, reference may be made to the Swiss '2000-Watt' study, where this is the sustained energy per capita for heat and electricity services and for transport. This shows that the present 6000 Watt/cap. of Switzerland/Europe could – by saving 4000 using known saving technologies – become 2000 – of which 1500 would come from renewables and 500 would represent the GHG emissions per capita that could be absorbed by the planet. (Ref. Jochem E. (ed), 2004, 'Steps towards a sustainable development', http://www.cepe.ethz.ch/publications/Jochem_WhiteBook_on_RD_energyefficient_technologies.pdf). Most notably, methane emissions arise in growing food plants (rice) and animals (ruminants – pigs, sheep, cattle). (Ref. FAO, 2006, 'Livestock's Long Shadow', Table 3.12. http://www.virtualcentre.org/en/library/key_pub/longshad/A0701E00.pdf).

Limits

For each energy service or appliance the theoretical lower limit of energy use should be determined by analysis in the knowledge of the scientific laws. Comparing this with that of best practice would identify the opportunities for energy R&D and quantify the scope for product development. Although almost all buildings, appliances and lighting were developed and built in the era of low-cost fossil energy, most have yet to receive such rigorous study. It has been done for lighting, and in theory, the limit for white light is an 'efficacy' of about 330 lumens per Watt. Moreover, unlike all other light sources, Light Emitting Diodes (LEDs) have the potential to approach this, and have already achieved nearly one-third. Compared with the existing lamp mix in the USA, white LEDs of 150-200 lumens per Watt are expected to halve the electricity used for a given amount of lighting. (Ref. Tsao J., 2003, 'Roadmap projects significant LED penetration of lighting market by 2010', Laser Focus World, May 2003. http://lighting.sandia.gov/lightingdocs/TsaoJYLaserFocus200303.pdf). This would also reduce the cooling loads in most large buildings.

Also for the heating of buildings, the research has already been done – on the Continent. The lowest economic limit of building heat loss has been determined – and codified as the Passive House standard. Compared with present building standards, this represents a reduction for space heating energy of about 90%. (Ref. Feist W., No Date, 'Passive Houses from Pilot to Mainstream in Germany', http://malmo.se/download/18.1f60430104c0456fc68000698/Feist.ppt, Slide 4). This has been demonstrated across Europe with thousands of dwellings, plus offices and schools. (Ref. Feist W. et al, 2001, 'CEPHEUS – Cost Efficient Passive Houses as European Standard', http://www.passiv.de/07_eng/news/CEPHEUS_final_long.pdf).

Exergy

The best use must be made of all forms of energy supply. This is even more important as we move from cheap but problematic fossil fuels to more costly but sustainable renewables. This means having proper regard to energy quality or 'exergy', where the ranking - low to high – is heat, fuels, electricity. Thermodynamics, engineering and markets ensure that higher quality energy is always higher in unit cost (before taxes). Hence the exergy of the energy carrier and the end-use should be matched, since mis-matching gives rise to energy losses. These have been quantified for the UK energy system in 1995, with the losses expressed as 'Thermodynamic Improvement Potentials'. For space and water heating, they were 38.7 mtoe/y and in road transport, 22 mtoe/y. These amounted to 17% and 9% = 26% of UK primary energy supply. (Ref. Hammond et al, 2001. 'Exergy Analysis of the UK Energy System', Proc. I Mech E, Vol. 215, 2001, Part A, p 141). Since the necessary measures have as yet been little implemented in the UK, the proportions will still be similar.

Space and water heating loads require only low temperatures. Humans have a body temperature of 37 C and for comfort occupied buildings should be around 20 C. Also tapwater needs heating from about 10 C to about 60 C. Therefore as an energy carrier, water at a flow temperature of say 70 C and a return temperature of say 40 C offers excellent 'exergy matching' with almost no energy losses. Hence when substituted for electricity or gas, it gives the highest energy savings. Moreover, for space and water heating it is the best conceivable and thus truly 'future proof'. When supplied to multiple buildings via a network of double-pipes, it is known as District Heating (DH).

Thus high quality energy must be used only where it is essential. For example, electricity is needed for lighting, drive motors, and electronics – i.e. appliances – but not for 'bulk' low temperature heating – space and water heating. However, electricity should also be used for cooking. This is because fossil gas is depleting and thus not sustainable. Also, biogas will be limited in quantity. In any case, due to its higher exergy, it is better used for Combined Heat and Power (CHP), transport fuel or as a chemical feedstock – e.g. for plastics.

Scale Effects

Both depletable and renewable energy supply measures are much more effective and much less costly in large scale units. This is widely true in engineering due to various scale effects, such as the 'square-cube' law, which affect both the performance and the specific (capital) cost per unit of output capacity. As ever, there are practical limits to the beneficial scale effects, but they do not usually apply in the ranges of interest here. All on-site renewable measures, such as micro wind turbines, micro-chp, solar water heating and heat pumps, are intrinsically small and thus adversely affected by scale effects. Conversely, off-site measures such as DH-CHP, large scale solar heat arrays and large wind turbines, can be 1000 to 100,000 times larger and thus very beneficially affected. (Ref. Taylor G., September 2007. 'Energy Criteria for Sustainable Energy Solutions', Slide 26. http://www.energypolicy.co.uk/Gordon_Taylor8e.pdf). However, networks must aggregate the building loads.

Large scale systems and networks also have higher reliability. They enjoy better design, commissioning, and operation by professionals. Moreover, they have effective 'redundancy' with additional plant for peak loads and emergencies. Furthermore, system maintenance and even fuel and energy changeovers - e.g. from fossil to renewable – need not affect the user. DH networks enjoy all these advantages. Also, many are equipped with large heat storage tanks capable of full output for e.g. eight hours in winter and 48 hours in summer. (Ref. Petersen M.K., 2004. 'Heat Accumulators', 'News from DBDH', 1/2004, p 4).

Among scale effects, all networks - water, gas, electricity etc. - experience diversity of demand. For DH networks, the 'diversity factor' is around 0.5. (Ref. Winter W. et al, T.U. Graz, 2001. 'Untersuchungen der Gleichzeitigkeit in kleinen und mittlere Nähwarmenetzen', 'Euroheat & Power', 09&10/2001. http://www.bios-bioenergy.at/uploads/media/Paper-Winter-Gleichzeitigkeit-Euroheat-2001-09-02.pdf). This is hugely important as it affects the capacity and hence the capital cost of the central plant - as well as the overall energy consumption. It is directly related to the variation in energy consumption across a sample of similar dwellings. (Ref. Feist W., No Date, 'Passive Houses from Pilot to Mainstream in Germany', Slide 15. http://malmo.se/download/18.1f60430104c0456fc68000698/Feist.ppt).

Variability

The electricity and heat demands of dwellings of supposedly identical design can vary appreciably. (See 'Scale Effects' above). For example, build quality can vary - affecting heat loss - as can the dwelling aspect - affecting solar gain. Also, the demands can change over time, with changes of households and as children arrive and leave.

Under the 'Merton Rule' and 'Zero Carbon' proposals, even with on-site renewable electricity measures, connection to the grid would still be permitted. Although the imports and exports are supposed to balance over the year, this connection could also cover the case of a high demand dwelling or household. If there is no such connection, this household would require more on-site electricity capacity, which would cost more. Yet this extra capacity might never be used by a low demand household, and therefore be wasted. However, for on-site renewable heat measures, connection to the gas or heat network is not foreseen. Hence the on-site capacity must cover the case of the high – indeed highest - demand household, which would cost much more than for the average demand. Yet this extra capacity might never be used by a low demand household, and therefore be wasted. If this extra capacity is not provided, a high demand household would be forced to rely on electric space and water heating for a satisfactory heat service. This would greatly increase the money cost - perhaps putting them back into fuel poverty - and also the fuel use and carbon emissions – the exact opposite of the primary policy objective.

Therefore satisfactory energy service, including heat, is only assured for all dwellings if they are connected to both electricity and gas or – preferably - heat networks. This allows the demands to be met with off-site measures with very low carbon, and at lower cost, due to the beneficial scale effects, including diversity.

System Effects

These apply to all on-site energy supply. Even with on-site renewable electricity measures, both the 'Merton Rule' and 'Zero Carbon' proposals permit grid connection. However, as any electrical engineer would know, this results in 'the worst of both worlds'. There is little or no saving in the cost of generation, transmission and distribution plant, since the on-site output can be zero. This occurs with PV at night, micro wind turbines in still air, and micro-chp when there is no heat demand. However, any on-site output reduces the load factor, and hence impairs the economics, of the central plant – i.e. the very business case on which it was built and is operating.

Heat pumps also have adverse system effects, particularly when using resistance peak heaters. Likewise, solar water heating would have adverse system effects if using electricity for backup heat. Again this is due to their low load factors, which require the electricity supplier to have generation, transmission and distribution capacity that is little used. For example, one heat pump system in the UK was reported as having an annual load factor of only 11% or less than 1000 full load hours per year. (Ref. BRE, 2000. 'Heat pumps in the UK – a monitoring report', Report GIR72. http://www.heatpumpnet.org.uk/files/gir72.pdf). Even with diversity, such loads would still be unattractive to the supplier. If such on-site systems were widely adopted, the electricity supplier would use a time of day and year tariff, or a maximum demand tariff, as already used for industry and commerce. This would compensate the central supplier, but increase considerably the costs to the site.

Measures Not Chosen

For sustainable energy solutions, the criteria are energy savings and low carbon energy supply with 'exergy matching', both with high EROIs, helped by large unit sizes, accommodation of variability and freedom from system effects. Thus measures that fail these criteria must be rejected outright. This includes all on-site renewable energy supply measures – save biomass heating. Also, people should be discouraged from spending their own money on them. The UK collectively lacks the time, money and – most critically – the energy to waste investing in measures that are either ineffective (or even counter-productive) or less cost-effective than others.

Using electricity for space and water heating involves a large mis-match of exergy, and hence very large losses of energy. Electric heating is often favoured by developers because it is apparently low in capital cost. However, the supply chain - generation, transmission, and distribution - is very high in capital cost, never mind the running – principally fuel – cost. Furthermore, neither on- or off-peak electric heating uses only low carbon nuclear power, since during the heating season considerable fossil fuelled generation is also necessary. Even for off-peak electric heating, this increases the weighted average carbon intensity above the annual average for the whole system.

Both nuclear electricity and natural gas have exergies that are unnecessarily high for space and water heating, and thus incur large energy losses. Moreover, being based on depletable fuels, they cannot be part of a sustainable future. Also they would be far too vulnerable to offer security of service. Nuclear power could fail at any time, whether through age - as has happened in recent months in the UK - or radioactive release - due to 'accident' or terrorism. Gas imports via long pipelines and LNG tankers could be diverted to markets prepared to pay more or be disrupted or stopped by attacks. Thus these energy options fail the 'Precautionary Principle'.

Some have proposed the use of hydrogen for space and water heating and for transport, often with fuel cells. However, for space and water heating, hydrogen has too high an exergy, so would suffer from large energy losses, much like gas. Moreover, for transport it is inferior to biofuels, synthetic liquid fuels and electricity via wires or batteries. (Ref. Bossel U. et al, 2003, 'The Future of the Hydrogen Economy: Bright or Bleak ?', http://www.energypolicy.co.uk/hydrogen.htm and Bossel U., No Date. 'Efficiency of Hydrogen Fuel Cell, Diesel-SOFC-Hybrid and Battery Electric Vehicles'. http://www.efcf.com/reports/E04.pdf).

Seeking Sustainable Solutions

Savings

Improvement of some of the building stock to the PH standard is both possible and necessary. This would reduce the space heating demand by about 90%. (See 'Limits' above). Clearly this should apply to all new buildings, starting as soon as possible. (Ref. Kondratenko I. et al, 2006. 'Potential for Energy and CO2 Emission Savings through the application of the Passive House Standard in Ireland'. http://erg.ucd.ie/pep/pdf/Irena_Kondratenko.pdf). Also, refurbishment of existing buildings to the PH standard is possible and has been confirmed by extensive measurements. (Ref. DENA, 2004. 'Besser als ein Neubau'. http://www.dena-energieausweis.de/page/fileadmin/waermewert/dokumente/niedrigenergiehaus.pdf). This is best applied to existing buildings beyond any planned future heat network. Hence there should be 'Heat Planning' for all towns and cities, as in Denmark. (Ref. Dyrelund A., 2000, 'Why Zoning? Why not just leave it all to market forces ?', 'News from DBDH', 2/2000, Page 16).

The case for DH

For large fuel and carbon savings, heat is best supplied from large units, such as CHP plants and solar heat arrays. (See 'Scale Effects' above). These require large heat loads and therefore the individual building heat loads need to be aggregated by networks. Of all energy carriers, District Heating (DH) offers the best 'exergy matching' to such loads. Hence when substituted for electricity or fossil fuel heating, it gives the highest energy and carbon savings.

For pre-insulated DH pipes, the flow temperature should not exceed 120 C. (Ref. Holm T. et al, 1998. 'Tests of expected lifetime for pre-insulated district heating pipes'. 'News from DBDH, 1/1998, p 6). Indeed, to lengthen the life of the pipe insulation and to increase the electricity efficiency of CHP plant and thus the Thermodynamic Heating Efficiency (THE) of the co-generated heat, it should be still lower. (See 'Thermodynamics' below). Moreover, if the temperatures are below 100 C, the pipes are not subject to 'Boiler Codes' (premium quality standards), and can thus be less expensive. This flow temperature is still more than sufficient for space and water heating and for heat-driven chillers for cooling. (See 'Cooling' below).

Broadband

The cost of DH could be offset by taking the opportunity to install optical fibre cables right to every building, giving extremely high bandwidth. (This is an old idea, proposed by the BRE many years ago). This would bring a large income from communications and entertainment services. It would also enable major savings in transport, due to e.g. tele-working and remote health services and monitoring. This would complement the transition to a home-work pattern where jobs and schools etc are all within reach of walking, cycling, and public transport. Both measures would help to reduce the fuel use and carbon emissions in the transport sector.

Cascading

In the UK, there are substantial demands for electricity for various uses and for heat at low temperatures - below about 100 C - for space and water heating. Moreover, separate generation of electricity in power stations and heat in gas boilers is hugely wasteful. To upgrade fossil fuels to electricity, thermodynamic conversion is needed, and the Laws of Thermodynamics dictate that there are unavoidable losses. Also, since practical implementations are less than perfect - though they are much better at large unit sizes - these losses are even higher. They amount to about 20% of the UK primary energy consumption, and are comparable to the entire heat demand for buildings. However, such reject heat need not be wasted. Most fossil power stations are located near the towns and cities that they supply with electricity. These facts prompt the idea of Combined Heat and Power (CHP). This is a simple idea, practised since the first power stations were built over 100 years ago. (Ref. Erlandsen E., 2004, 'One hundred years of CHP', 'News from DBDH', 1/2004, p 14). By cascading the energy from power to heat generation, rather than generating them separately, it can effect huge savings in fuel consumption and carbon emissions.

Synergies

The European Council has set an overall carbon reduction target of 20% by 2020. As part of this, the renewable energy targets for the UK are set at 15% overall and 10% for biofuels in transport. The UK has huge opportunities in renewable electricity, particularly with large wind farms, but has so far achieved little with biofuels. Therefore the opportunities in renewable heat should be explored. However, to exploit all the synergies, savings and supply measures for heat services, transport, and electricity services should be considered together. This is invariably done for chemical plants, using 'Pinch' methods and 'Process integration'. The synergies include 'cascading' as in the co-generation of heat and power by CHP plants, fired with fossil fuels, municipal waste and biomass, supplying heat to DH networks. Also, solar and geothermal heat could best contribute via DH. Moreover, 'surplus' wind electricity could be used - on an interruptible basis - to synthesise liquid transport fuels and supply heat to DH networks. Hence to maximise the synergies, the design methodology should not impose allocation constraints, but seek to achieve the committed targets without them. Such unconstrained solutions should ensure the best allocation of savings and renewable measures between heat and electricity services and transport. This would give the lowest overall money and energy costs and hence the highest certainty of achieving the target. (Ref. Taylor G., 2002. 'Energy Solutions for 60% Carbon Reduction'. http://www.energypolicy.co.uk/epolicy.htm).

The case for CHP

In the UK, the performance of CHP is reported using only a convention. (Ref. BERR, 2007, 'Digest of United Kingdom Energy Statistics 2007', Paragraph 6.34. http://stats.berr.gov.uk/energystats/dukes07.pdf). However, it does not refer to thermodynamics, so is wrong. Moreover, the true merit of CHP is revealed not by First Law analysis but only by a Second Law analysis, where this refers to the Laws of Thermodynamics.

Thermodynamics

All CHP plant embodies a 'power cycle', such as Rankine for steam turbines or Brayton for gas turbines and both for Gas Turbine Combined Cycle (GTCC) plant, and a 'Virtual Heat Pump' cycle - effectively a reversed Rankine cycle within the steam turbine. In CHP operation, a small loss of electrical output is used to upgrade the exergy or temperature of the hitherto wasted reject heat from just above ambient temperature (say 20 C) of 'condensing' operation to a useful level (often 100 C or less), by 'back-pressure' operation. (There is little or no loss of electricity output with CHP plant based on reciprocating Internal Combustion Engines (ICEs), because the bottom temperature is higher (about 100 C) and the electricity efficiency is already lower).

For a CHP unit supplying co-generated heat, the 'source' for the Virtual Heat Pump (VHP) is the water returning from the heat load and the 'sink' is the water flowing to the heat load. Moreover, for GTCC units the power cycle has a high top temperature (over 1000 C), so that raising the bottom temperature from condensing (power-only) to back pressure (CHP) operation incurs only a tiny loss of electricity output. Hence for GTCC units of around 100 MWe or more, the heat out over the electricity loss - i.e. the Coefficient of Performance (COP) of the VHP - is very large at around 8 or more. The real merit of CHP becomes apparent when the COP is multiplied by the electricity efficiency of the power cycle, say 0.5, to determine the heat out over the increment of fuel-for-heat, which product may be called the 'Thermodynamic Heating Efficiency' (THE) = 8 x 0.5 = 4. This value applies to heat at the CHP plant boundary. After accounting for the small contribution from Heat Only Boilers for peak loads, and for the DH network heat losses, the THE of such DH-CHP is about 3.3, while the average gas efficiency of the existing boilers has been put at 0.65. (Ref. PIU, 2002. 'Energy Scenarios to 2020'. http://www.pm.gov.uk/files/pdf/PIUe.pdf). Hence the saving of fuel and carbon for heating would be (1 – 0.65/3.3) = 0.8 or 80%. (Ref. Taylor G., 2002, 'Energy Solutions for 60% Carbon Reduction', Section 3.9. http://www.energypolicy.co.uk/epolicy.htm).

Although when existing steam and GTCC power stations operate as CHP plants, they incur a small drop in electricity output, this can be largely or fully offset by DH displacing electric space and water heating. In the UK, this amounts to about 9% of the energy for heat. Moreover, due to the high carbon intensity of electricity, such displacement by DH-CHP reduces fuel use and carbon emissions even more – about 85%. (Ref. Taylor G., 2002, 'Energy Solutions for 60% Carbon Reduction', Section 3.10. http://www.energypolicy.co.uk/epolicy.htm).

A major study comparing several forms of CHP/DH with the alternative of separate generation was carried out in 2005. (Ref. Parsons Brinckerhoff et al, 2005. 'A Comparison of Distributed CHP/DH with Large-Scale CHP/DH', http://www.svenskfjarrvarme.se/download/3477/8dhc-05-01_distributed_vs_large-scale_chp-dh.pdf). However, the published results 'masked' the true merit of CHP by giving only the savings for electricity and heat together. Thus the saving in gas and CO2 emissions for City-wide CHP/DH versus separate generation was 27%. However, CHP is not about electricity, nor electricity and heat, but about heat alone. When the CO2 emissions are adjusted to a heat-only basis and to reflect Continental practice but displacing UK domestic boilers, the saving for City-wide CHP/DH versus separate generation of heat is about 80%. (See Appendix A).

'A recently developed and very comprehensive study for Europe very clearly shows that average Primary Resource Factor (PRF) for district heating is much lower than common energy systems in Europe by a factor 4.5. Utilization of excess heat and renewables lowers the value of PRF'. (Ref. Gullev L. 2007, 'The Chairman's Column', DBDH Journal, 4/2007, p 2). The carbon emissions are closely proportional to the PRF. (Ref. Wirgentius N., 2006, 'Primary Resource Factor – for systematic evaluation of heating and cooling options', Slide 9. http://www.euroheat.org/documents/Conference2006Presentations/8.Wirgentius.ppt). Hence the fuel and carbon savings for DH-CHP plus some renewables is (1 – 1/(4.5)) = 0.78 or 78%. This is very close to the above-mentioned value of 80%.

Water

The visible proof of losses from power stations are the huge cooling towers and the invisible proof is the heat rejected to rivers and the sea. Moreover, the cooling towers are 'wet' and require a constant supply of fresh water to evaporate and so carry away the heat. This can often be seen as vapour rising from the cooling tower to the cloud base above. When operated as a CHP plant, the DH in the town or city provides the cooling. Hence the cost of DH-CHP could be offset by the savings of water otherwise used in wet cooling towers – i.e. the cost of an equal amount of water capacity. This is a huge item, accounting for some 44% of the fresh water abstraction in the UK. (Ref. POST, February 2006, 'Balancing Water Supply and the Environment'. http://www.parliament.uk/documents/upload/postpn259.pdf). Meanwhile, the Code for Sustainable Homes, Level 6, requires water consumption to be reduced from 120 to 80 litres/person/day – i.e. by 33%. (Ref. DCLG, 2006, 'Code for Sustainable Homes', page 9. http://www.planningportal.gov.uk/uploads/code_for_sust_homes.pdf). Thus DH-CHP would be more effective in saving water while not reducing that supplied to homes.

Other Heat Sources

Of all energy carriers, only DH enables other sources of heat to be harnessed at large scale or at all, including CHP fuelled by municipal waste and biomass, industrial reject heat, solar heat and geothermal heat. (Ref. Sahlin T., 2006. 'Riding the Wind of Change', Slide 6. http://www.euroheat.org/documents/Conference2006Presentations/14. Sahlin.ppt and Werner S., 2006. 'Ecoheatcool Work Package 4: Possibilities with more district heating in Europe', p 40. http://www.euroheat.org/ecoheatcool/documents/Ecoheatcool WP4 Web.pdf). For example, waste-to-energy facilities covered about 18% of the total district heating in Denmark in 2004. (Ref. Graasboll S., 2006, 'Waste management in Denmark'. 'News from DBDH', 4/2006, p 4). Also, in Denmark, solar heat arrays of 250 m2 and above are profitable on a commercial basis, without subsidies. Therefore arrays of 1000s to 10,000s of m2 are being built. (Ref. Steffensen H., 2007, 'EU aim at great expansion of large-scale solar thermal plants', DBDH Journal, 4/2007, p 15). Even 'surplus' wind electricity could be used to supply heat to DH networks. (Ref. Taylor G., 2002. 'Energy Solutions for 60% Carbon Reduction', Section 5.4. http://www.energypolicy.co.uk/epolicy.htm). Geothermal heat is site-specific but is available for many cities, including Reykjavik, Copenhagen, Paris and Southampton. For Western Copenhagen, with DH-CHP fuelled by fossil fuels, municipal waste and biomass, the Primary Resource Factor is already only 0.13. (Ref. Gullev L., 2007, 'The Chairman's Column', DBDH Journal 4/2007, p 2). Assuming a pre-existing boiler efficiency of say 75%, giving a PRF of 1/0.75 = 1.3, the carbon saving is already (1 – 0.13/1.3) = 90%.

A major study comparing several forms of CHP/DH with the alternative of separate generation was carried out in 2005. (Ref. Parsons Brinckerhoff et al, 2005. 'A Comparison of Distributed CHP/DH with Large-Scale CHP/DH',

http://www.svenskfjarrvarme.se/download/3477/8dhc-05-01_distributed_vs_large-scale_chp-dh.pdf). As a variation, this study considers the case of municipal waste arising in the city being used as part of the fuel. When the CO2 emissions are adjusted to a heat-only basis and to reflect Continental practice but displacing UK domestic boilers, the saving for City-wide CHP/DH could become about 87%. (See Appendix A).

Cooling

District Cooling (DC) of buildings can be 'free' – from lakes, rivers and seas – and from heat-driven chiller plants. These may be located either centrally, at the CHP plant, or distributed in or near the buildings with major cooling loads. Absorption chillers can be driven by water at flow temperatures as low as 75 to 80 C. (Ref. Krawinkler R., 2007, 'Summerheat – improving the load for CHP plants during summer', Slide 6. http://www.eu-summerheat.net/download_files/03_Presentation_EHP_Bled_Nov_2007.pdf). A low COP of the chiller is of less importance than keeping down the DH flow and return temperatures. (See 'The Case for DH' above). In any case, ample DH is available in summer, particularly from municipal waste burnt in CHP and boiler plants, which must continue year round. The advantage of DC may be shown by comparing the respective 'Primary Resource Factors', to which the carbon emissions are closely proportional. (Ref. Wirgentius N., 2006, 'Primary Resource Factor – for systematic evaluation of heating and cooling options', Slide 9. http://www.euroheat.org/documents/Conference2006Presentations/8.Wirgentius.ppt). While that for electrically-driven chiller plant in the building is about 1, that for DC from heat-driven chillers is about 0.15. (Ref. Ditto, Slide 4). This represents a huge - 85% - saving of fuel use and carbon emissions as well as valuable extra business for the DH-CHP plant and network. Piped distribution of both 'free' and heat driven absorption cooling is advancing rapidly on the Continent. (Ref. Dalin P. et al, 2006. 'Ecoheatcool Work package 5 - Possibilities with more district cooling in Europe', http://www.euroheat.org/ecoheatcool/documents/Ecoheatcool WP5 Web.pdf and Dalin P., 2007. 'District Cooling : Innovative Kǘhlung und Beitrag zum Klimaschutz'. http://www.eu-summerheat.net/download_files/07_EHP_District_Cooling_WSH.pdf).

Buildings Beyond the Heat Networks

Buildings to earlier standards beyond the heat networks could use biomass heating, from a log, chip, or pellet boiler. For those built to the Passive House standard beyond the heat networks, the remaining 10% of space heating, and all water heating could also come from biomass. An alternative – especially for smaller demands - could be a boiler burning biodiesel or even glycerine, a by-product of biodiesel production.

High Temperature Process Heat

As energy prices rise, industrial process optimisation and integration will yield increasing energy savings. This will be necessary for both competitiveness and carbon reduction.

Heat for processes from say 90 C to say 1000 C should come from biogas – as offering the best 'exergy matching'. This would be produced in large plants – either on-site or shared – by gasifying biomass, usually wood chips or pellets. In the GoBiGas project in Gothenburg, the energy balance is expected to be 70% biomethane, 20% to district heating, and only 10% energy losses. (Ref. Svensen B. 2007, 'Biomethane for vehicles creates a new industry', Slide 20. http://www.businessregiongoteborg.com/download/18.5534da6a116154d21fc80003045/Biomethane+for+vehicles+creates+a+new+industry-++BRG.pdf). Moreover, in an excellent example of 'synergy', the biogas would be supplied to industry to replace oil (for high temperature heat), as well as in winter to a large CHP plant and in summer for gas-powered vehicles. (Ref. Hedenstedt A., 2007, 'Large Biomethane Potential from Gasification of Forest Industry Waste products'. http://www1.stocon.se/cleanvehicles/9/common/getFile.asp?FileId=59291&ObjId=59443). Gothenburg Energy intends to replace all natural gas they use by biogas by 2050. (Ref. Gunnarsson I., 2005, 'Production and refining of biomethane: Some projects for the future', Slide 7. http://www.bioenergydays.com/pdf_file/lecturer_eng/pm_1_Biofuel/I_Gunnarsson_Biomethane.pdf). However, they supply DH for space and water heating, so most of the biogas will be for the above uses. Since the UK has far less scope for growing biomass, it would have to reserve almost all biogas for only such uses.

For processes above say 1000 C or where extreme cleanliness is required, electric heating may be used. In any case, increasing renewable electricity will be needed to reduce the carbon intensity to zero for sustainability. Higher temperature processes may account for considerable amounts of heat. However, many such processes reject heat at temperatures above those required for space and water heating. This can be harnessed by DH networks and so reduce fuel use and carbon emissions. In Gothenburg, such heat accounted for 58% of that produced for DH in

2005. (Ref. Gunnarsson I., 2005, 'Production and refining of biomethane: Some projects for the future', Slide 4. http://www.bioenergydays.com/pdf_file/lecturer_eng/pm_1_Biofuel/I_Gunnarsson_Biomethane.pdf).

The Measures Chosen

The planning end-point should be sustainability and the measures chosen should meet all the criteria for sustainability. These are energy services via savings approaching the theoretical limits and low carbon energy supply with exergy matching, both with high EROIs, taking advantage of beneficial scale effects and diversity, accommodating variability, and freedom from adverse system effects. These are satisfied by the measures below.

All new buildings should be built to the Passive House (PH) standard, and some existing buildings refurbished to this standard. All buildings beyond the heat networks should use biomass or biofuel heating.

For heat services in towns and cities, the object would be to 'squeeze out' gas and electric heating – between PH standards and biomass, growing inward from the periphery, where the heat load density is too low for DH networks, and DH-CHP growing outward from the centre, where the heat load density is high. The large CHP plants would be fuelled initially with gas (or coal) and later with municipal waste and biomass/biogas. Also, the DH networks would use other sources of heat, including industrial reject heat, large-scale solar heat, possibly 'surplus' wind electricity and – where feasible – geothermal heat. District Cooling (DC) of city centre buildings would be by 'free cooling' from lakes, rivers and the sea where available, and otherwise driven by heat from CHP and other DH. These should give fuel and carbon savings of 80 to 100%. This would avoid the need to demolish all our existing towns, cities and heritage buildings and rebuild them to Passive House standards.

For industrial process heat at higher temperatures, even after energy savings, biogas and renewable electricity would be required. However to reduce demand, there will be a major shift from primary to recycled materials.

Estimates of Potential Savings

The Heat Call for Evidence estimates the 2020 carbon savings in the domestic sector, based on present policies, as 39.3 MtCO2/y. (Ref. HCE, para 33). Moreover, going further would require more expensive measures that could cost more than £ 20,000 per household. (Ref. HCE, para 38). Regarding DH, for 'District heat with remote supply', it mentions a potential carbon savings (rate) of 80%. (Ref. HCE, para 39, Table 2.1). However, for 'Gas CHP district heating' it also mentions carbon savings (rates) of 6% relative to gas and 46% relative to electricity. (Ref. HCE, para 196, Table 6.2). These very different values are hard to resolve. As for the potential (absolute) carbon savings, it mentions a 'Shorter Term Potential' for DH of 'round 1 MtCO2/y'. (Ref. HCE, para 206). It also mentions a 'significant long term potential' for DH of 5.5 to 6.5 million homes, with carbon savings in the order of 19 MtCO2/y. (Ref. HCE, para 258).

The true potential saving from DH, based on the correct understanding of CHP and the best Continental practice, is much greater. (See Appendix B). The DH network is assumed to reach 80% to 100% of the heat loads. For DH from CHP, the Heat Call for Evidence gives the saving rate for 'district heat with remote heat supply' as 'up to 80%'. (Ref. HCE, para 39, Table. 2.1). Moreover, such a value is confirmed by several other sources. (See 'Thermodynamics' above). Hence the CHP saving rates are assumed to be about 80%. The resulting potential carbon saving for DH-CHP is 121 MtCO2/y. Moreover, the same infrastructure could use industrial reject heat, municipal waste, biomass, solar heat and geothermal heat, which could increase the carbon saving rate to 100%. With this, the potential carbon saving is 154 MtCO2/y.

For such a DH-CHP infrastructure, the build-up period could be about seven years. (Ref. Parsons Brinckerhoff et al, 2005. 'A Comparison of Distributed CHP/DH with Large-Scale CHP/DH', Section 7. http://www.svenskfjarrvarme.se/download/3477/8dhc-05-01_distributed_vs_large-scale_chp-dh.pdf).

20% of residential buildings are assumed to be beyond the DH networks. These are assumed to be to Passive House standards with biomass or biofuel heating and to earlier standards with biomass heating, giving a potential carbon saving of 100% - i.e. 19 MtCO2/y.

Half the industrial heat is assumed to be at higher temperatures. That from say 90 C to say 1000 C is assumed to be from biogas and that from say 1000 C upwards or requiring extreme cleanliness from renewable electricity. The potential carbon saving is 100% - i.e. 47 MtCO2/y. However, many such processes reject heat at temperatures above those required for space and water heating. This could be 'cascaded' into DH networks and so reduce fuel use and carbon emissions.

Thus these measures could achieve the carbon saving of 220 $MtCO_2/y$ – i.e. the 100% needed for sustainability.

Modelling

To evaluate mixes of measures as solutions, especially when taking advantage of all the synergies, they must be represented in a mathematical 'model'. Only by using the language of mathematics, numbers and formulae, can all parties communicate with the greatest clarity. In addition, a model enables users to get a 'feel' for the problem – thus gaining valuable insights as to which avenues are the most rewarding. To this end, the model should be simple but not simplistic. That is, it should not be highly detailed - like a MARKAL model - with many measures included - often supply - but also many measures omitted - often savings. Inclusion of many measures within the model may give the illusion of completeness where none exists. Moreover, it makes the model too complex and opaque for practising engineers to check and for policy makers to use. Instead, the list of measures should be whittled down outside the model. (See 'Measures not Chosen' above). Furthermore, since the challenges are climate and energy, the accounting units should be not money but energy and carbon. Money values are subject to inflation and exchange rates. Conversely, the energy and carbon attributes of energy saving and supply measures can be stated with certainty, since the science is unchanging and the mature technologies change only slowly. Thus all the formulae should be consistent with the laws of science.

Such a model can be built as a spreadsheet, which has the huge advantage that it can be run on any PC using Excel and 'The Solver'. Only the end point need be considered, since if there are valid solutions for this, then there should be solutions throughout the transition. Such a model can be used to seek - for a given carbon target - a 'solution space' within ranges of key parameters relevant to policy, such as the amounts of indigenous wind electricity, home-grown biomass and imported biomass/biofuel. It can also be used to explore the 'sensitivities' or trade-offs between the key parameters. (Ref. Taylor G., 2002. 'Energy Solutions for 60% Carbon Reduction', Section 11. (http://www.energypolicy.co.uk/epolicy.htm).

Discussion of Results

The estimates above are based only on 'cascading' – i.e. DH with CHP. For this measure, the Heat Call for Evidence gives potential carbon savings of 1 and 19 $MtCO_2/y$. Yet it also gives the savings rate for 'district heat with remote heat supply' as up to 80%. Based on meeting 80% of the residential, 100% of the commercial/public sector and half the industrial heat load with DH, with a CHP saving rate of about 80%, the potential carbon saving is 121 $MtCO_2/y$. Moreover, the DH-CHP infrastructure could use industrial reject heat, municipal waste, biomass, solar heat and geothermal heat to increase the carbon saving rate to 100% and the potential carbon saving to 154 $MtCO_2/y$. Buildings outside the DH networks could use Passive House standards and biomass heating, giving a potential carbon saving of 19 $MtCO_2/y$. Higher temperature industrial process heat could come from biogas and renewable electricity – so saving the remaining 47 $MtCO_2/y$.

With fuel and carbon savings of 80 to 100% and a 'build-up' time of only seven years, the potential magnitude and speed of the savings with DH-CHP etc. would exceed those of any other measure. No other measures could achieve such carbon saving with our existing towns, cities and heritage buildings. Significantly, it is already used increasingly in over 1000 cities on the Continent. (Ref. DHCAN, No Date. 'The Case for District Heating: 1000 Cities Cannot be Wrong!'. http://projects.bre.co.uk/DHCAN/pdf/PolicyGuide.pdf). Indeed, the Danish Government has named it as the most important single measure for fuel and carbon savings and even in 1998, DH-CHP had reduced Denmark's total (CO_2) emissions by 10%. (Ref. Auken S., 1998, 'CHP – an important contribution to solving climate changes', 'News from DBDH', 1/1998, p 1). Thus it would be essential for meeting the UK climate and energy objectives, including sustainability.

For a more complete calculation, including the other 'synergies', modelling is required – aimed at 100% carbon saving. Meanwhile a study with results for 60% carbon savings is available. (Ref. Taylor G., 2002. 'Energy Solutions for 60% Carbon Reduction'. http://www.energypolicy.co.uk/epolicy.htm). The qualitative consideration of energy measures and the quantitative determination of solutions are more complete than any study yet published by or for Government. Moreover, the energy measures chosen are capable of achieving a carbon saving of 100%, as needed for sustainability.

For the UK to address the climate and energy issues adequately requires studies of a much higher order than those that have informed the Heat Call for Evidence or even that mentioned above. Such work should be carried out by at least three consulting engineering firms, with at least two from the Continent, who are already knowledgeable in the field and have all the evidence at hand. With the knowledge that sustainable solutions were available, Government would then be able to invite Energy Service Companies (ESCOs) to take up franchises for all the UK energy markets, subject to absolute Carbon Emission Obligations. These would be based on market shares of the national carbon emission milestones on the road to sustainability. This framework would thus ensure that the milestones and targets were met on time.

Delivery of Solutions

ESCOs

The Stern Review Report pointed out that significant investments would be necessary to mitigate climate change. Although far less costly than the consequences of inaction, they could amount to roughly 1% of world GDP by 2050. (Ref. Stern N., 2006, 'The Economics of Climate Change'. Executive Summary, Fig. 3. http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/sternreview_index.cfm).
The Energy White Paper 2007 has the strategy point of providing legally binding targets for the whole UK economy. (Ref. DTI, 2007, 'Meeting the Energy Challenge', p 9, http://www.berr.gov.uk/files/file39387.pdf). However, such investments and targets could never be met by householders (owner-occupiers), house-owners (of rented property), or small and medium businesses. They would number millions (requiring a huge bureaucracy), have no access to low-cost, long-term capital (other than mortgages) and thus require considerable inducements from the Treasury (yet more bureaucracy and public expense), and have very high 'political' risks, since they are all voters. Moreover, they would require huge amounts of information (yet more bureaucracy and public expense), which most could not understand. After all, they have other priorities, such as earning a living or running businesses and raising families.

Hence such investments and targets could only ever be met by Energy Service Companies (ESCOs) contractually subject to absolute Carbon Emissions Obligations (CEOs). The ESCOs could be local authorities, private businesses such as utilities, or partnerships thereof. Moreover, such a framework would require the minimum of bureaucracy, impose no costs on the Treasury, and have no 'political' risks, since ESCOs are not voters.

ESCOs are already active in Europe, with 25 in Austria, 4 in Belgium, 500-1000 in Germany, 6-12 in Sweden and 20 in the UK. (Ref. P. Bertoldi et al, No Date, 'How are EU ESCOs behaving and how to create a real ESCO Market?', http://www.cenerg.ensmp.fr/english/themes/mde/pdf J Adnot/pdf12.pdf). Perhaps the best-known in the UK is that established by Allan Jones in Woking. This is Thameswey Energy, a joint venture between Woking Borough Council and Xergi Limited, which last is owned by Xergi A/S of Denmark.

Once energy solutions meeting the criteria for sustainability have been found by the studies from the consulting engineering firms, Government should supply them to candidate ESCOs with the following proposition:

● A series of milestones that would deliver the Government's carbon targets, both national and international, up to 100% for sustainability.

● A framework of franchises for each energy market – heat, electricity, transport fuels. Depending on the number, each could have a turnover of up to a billion pounds a year though most would be far less.

● These franchises would be held by ESCOs, subject only to meeting the CEOs at each milestone. If they failed, the franchise would be withdrawn and put up for new bids.

The CEOs must be delivered by energy savings and supply measures, and only within the UK. Measures under Joint Implementation and the Clean Development Mechanism would not address the policy objectives of security of energy service and the elimination of fuel poverty within the UK. However, trading of carbon credits or certificates could be permitted at the margin - to reward those ESCOs who outperformed their obligations and penalize those who under-performed. This would increase the certainty of the national milestones and targets being achieved.

Within such a framework, DH-CHP and the other measures – all chosen by the ESCOs to meet their contractual obligations - could be rolled out in every sizeable town and city in the UK at once, using local labour.

Conclusions

As noted in the Stern Review and elsewhere, both climate and energy require prompt action. The end-point for all planning, including climate and energy planning, must now be sustainability. This requires a complete energy transition, with a 100% reduction in carbon emissions. The amount of energy and the effectiveness with which it is invested in the energy infrastructure will directly determine the level of sustained energy services. Hence the measures chosen must be limited to those that can best meet these objectives. These include not on-site measures but widespread District Heating from large-scale Combined Heat and Power plants, as in over a thousand cities on the Continent. This offers carbon savings of 80 to 100%, while District Cooling offers 85 to 100%. Beyond the heat networks, buildings should be constructed or refurbished to the Passive House standard and use biomass heating. Higher temperature process heat could come from biogas and renewable electricity, again with 100% carbon savings. These measures for heating and cooling best offer the carbon savings of 100% needed for sustainability.

The only purpose of Government evaluating the various measures for fuel and carbon saving is to determine whether and what solutions exist for the committed targets and sustainability. In view of their importance for UK climate and energy policy, these findings should be confirmed by much more extensive studies. Such work should be carried out by at least three consulting engineering firms, with at least two from the Continent, who are already knowledgeable in the field and have all the evidence at hand. With the knowledge that sustainable solutions were available, Government would then be able to invite Energy Service Companies (ESCOs) to take up franchises for all the UK energy markets, subject to absolute Carbon Emission Obligations. These would be based on market shares of the national carbon emission milestones on the road to sustainability.

With Government having set the appropriate framework, delivery of the lower carbon emissions should be left to the ESCOs and their professional engineers. They have access to the necessary low-cost, long term funds and the knowledge and skills – and the incentive - to determine and implement the 'best' carbon saving measures on time.

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Appendix A – Adjusting Carbon Saving for DH-CHP to Heat-Only Basis

A major study comparing several forms of CHP/DH with the alternative of separate generation was carried out in 2005. (Ref. Parsons Brinckerhoff et al, 2005. 'A Comparison of Distributed CHP/DH with Large-Scale CHP/DH', http://www.svenskfjarrvarme.se/download/3477/8dhc-05-01_distributed_vs_large-scale_chp-dh.pdf).
From p 40, Figure 9A, the CO2 emissions for electricity and heat for the 'City-Wide' CHP/DH scheme are 0.97, while those for the 'Alternative' scheme of separate generation are 1.32 MtCO2/y. This gives a CO2 saving rate of (1.32 – 0.97)/1.32 = 0.27 or 27%.

The CO2 emissions for DH-CHP may be adjusted to a heat-only basis by subtracting those for the electrical demand. From p 26, Table 5.4, the 'Sector electricity demand' for the City-wide CHP/DH scheme and for the 'Alternative' scheme is 1,936,653 MWh/y. From p 91, Table F-10, the emissions factor (CO2) for imported electricity is 390 g/kWh = 0.39 tCO2/MWh. Hence the CO2 emissions for the electrical demand are 1,936,653 x 0.39 = 755,294 tCO2/y = 0.7553 MtCO2/y. Therefore the CO2 emissions for heat-only for the 'City-wide' CHP/DH scheme are 0.97 – 0.7553 = 0.2147 and for the 'Alternative' scheme are 1.32 – 0.7553 = 0.5647 MtCO2/y. This gives a CO2 emissions saving for City-wide CHP/DH versus separate generation of (0.5647 – 0.2147)/0.5647 = 0.62 or 62%. However for a CCGT CHP plant of about 400 MWe, the Z-factor would be about 8.4. (Ref. Frutschi H.U., 1996, 'Optimal Utilization of the Work Potential of Fuels and Renewable Energy with Combined Cycle Power Plants', ABB Review, 5/1996, pp 33-39). From p 26, Table 5-4, the CHP Electrical Efficiency is 51% on the Higher Heat Value. Therefore the product, the Thermodynamic Heating Efficiency would be about 4.2. Moreover in Continental practice, the share of useful heat from CHP would be not 70% but more like 95%. Hence the share from Heat Only Boilers would be only about 5%. (Ref. 'News from DBDH', 1/2001, p 14). These would increase the CO2 emissions saving to about 73%. Furthermore, the BRE has estimated the gas efficiency of existing domestic boilers in the UK as about 65%. (Ref. PIU, No Date, 'Energy Scenarios to 2020', Footnote 15. http://www.pm.gov.uk/files/pdf/PIUe.pdf). With this instead of 84 or 86%, the CO2 emissions saving would be increased to about 80%. (Ref. Taylor G., 2002, 'Energy Solutions for 60% Carbon Reduction', Section 3.9. http://www.energypolicy.co.uk/epolicy.htm).

As a variation, this study considers the case of municipal waste arising in the city being used as part of the fuel. From p 41, Figure 9B, the CO2 emissions for electricity and heat for the 'City-wide' CHP/DH are 0.93 MtCO2/y. Compared with those above, the CO2 emissions saving is 0.97 – 0.93 = 0.04 MtCO2/y. This could reduce the heat-only CO2 emissions from e.g. 0.5647 x (100 – 80)/100 = 0.1129 by 0.04 to 0.0729 MtCO2/y. The CO2 emissions saving rate for City-wide CHP/DH versus separate generation would be (0.5647 – 0.0729)/0.5647 = 0.87 or 87%.

Appendix B – Estimated Potential Carbon Savings

The Heat Call for Evidence gives the projected carbon emissions from heat in 2020 as about 220 MtCO2/y. (Ref. HCE para 17, Fig. 1.5). Of this, residential is 42%, commercial/public sector is 15% and industrial is 43%. (Ref. HCE para 17, Fig. 1.4). For simplicity, cooking is neglected in these estimates, but is assumed to be electric, from renewable electricity. Industrial heat is assumed to be half at low temperature (for buildings and low temperature processes up to say 90 C) and half for high temperature processes.

The DH network share rates are assumed to be 80%, 100%, and 100% (with the higher figure being due to the large loads and urban locations). For DH from CHP, the Heat Call for Evidence gives the savings rate for 'district heat with remote heat supply' as up to 80%. (Ref. HCE, para 39, Table. 2.1). Moreover, such a value is confirmed by several other sources. (See 'Thermodynamics' above). Hence the CHP saving rates are assumed to be 80%, 77%, and 77% (with the lower figure being due to more efficient existing boilers). The potential carbon savings are: (220 x 42% x 80% x 80%) + (220 x 15% x 100% x 77%) + (220 x 43%/2 x 100% x 77%) = 121 MtCO2/y. Moreover, the DH-CHP infrastructure could use industrial reject heat, municipal waste, biomass, solar heat and geothermal heat, which could increase the carbon saving rate to 100%. With this, the potential carbon savings are: (220 x 42% x 80% x 100%) + (220 x 15% x 100% x 100%) + (220 x 43%/2 x 100% x 100%) = 154 MtCO2/y.

20% of residential buildings are assumed to be beyond the DH networks. These are assumed to be to Passive House standards with biomass or biofuel heating and to earlier standards with biomass heating, giving a potential carbon saving of 100% - hence (220 x 42% x 20% x 100%) = 19 MtCO2/y.

Half the industrial heat is assumed to be at higher temperatures. That from say 90 C to say 1000 C is assumed to be from biogas and that from say 1000 C upwards or requiring extreme cleanliness from renewable electricity. The potential carbon saving is 100% - hence (220 x 43%/2 x 100%) = 47 MtCO2/y.