ABSTRACT

This paper focuses solely on domestic heating. It shows that in order to meet the obligations of the Climate Change Act, and also the policy objectives for aviation by 2050, the UK's domestic heating has to be completely decarbonised. This can either be done by electricity, or perhaps using new technologies to synthesise methane or hydrogen using spare summer electricity. No other renewable resources, such as biomass or biogas, can make other than marginal contributions.

The fundamental problems are twofold – generating the required energy, and meeting the peak power demands. The solutions dwarf the challenge of decarbonising the existing electricity grid. Both of these problems are essentially intractable with current technology.

The problems can be alleviated by the extensive, and expensive, use of insulation and heat pumps – no other current technology will make other than a very marginal contribution. However even the most optimistic assessment of the potential savings leaves a new carbon free power requirement that is greater than the entire current generating capacity of the UK. European connection is unlikely to help.

There are ways to approach the solution, but they involve intense, well funded, research programs that consider the entire energy system as a whole unit – from power source to house thermostat. The market alone cannot deliver the degree of cohenernce needed – it will require substantial Government involvement and support.

There are also policy measures which could be implemented quickly and cheaply that would be more effective than the existing RHI and Green Deal in the domestic sector, and would help accelerate substantially the decarbonisation of heat.

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BACKGROUND

1. This paper looks purely at domestic heating – though its conclusions relate equally to all building heat. There are a number of factors that need to be highlighted prior to any self-consistent discussion of heat.

THE LEGAL REQUIREMENTS ESTABLISHED BY THE CLIMATE CHANGE ACT.

2. To achieve a sustainable level of GHG emissions spread equitably around the world, UK emissions need to be cut around 80%-90% from 1990 levels. Stern cites sustainable global emissions of around 20GT/yr of CO_2(e), which if spread across 11 billion people gives 1.8t CO_2(e) per capita[1]. This is consistent with the Climate Change Act, which mandates an 80% cut in GHG emissions by 2050.

3. Achieving 80% reduction must account for sectors will be unable to achieve this. Agriculture and shipping are problems but aviation is the biggest challenge. In 2009 the government set a goal for aviation emissions in 2050 to be no higher than in 2005, at 37.5 million tonnes of CO_2/yr. If this is achieved, and non-CO_2 emissions are reduced by 70%, then according the Committee on Climate Change (CCC) the rest of the economy should cut CO_2 emissions[2] by 90% from 1990 levels to meet the 80% economy wide target. This requires emissions of CO_2 to reduce from 590 million tpy 1990 to 59 million tpy by 2050.

4. One critical caveat in the CCC Aviation report is that their analysis does not include the non-CO_2 emissions from aviation, though they stress that these should be included. A widely used estimate is that the non-CO_2 component is approximately equal to the CO_2 component. Adding this increases the amount of aviation emissions allowed in 2050 by 37.5Mt, but reduces allowable emissions from the rest of the economy by 30Mt[3]. Thus CO_2 emissions have to be reduced from 59Mt/yr to 29Mt/yr to accommodate the proper calculation of aviation emissions.

5. 2011 CO_2 emissions were 459Mt for a population of 61 million – or 7.5 tonnes of CO_2 per person. The Office for National Statistics projects a population of 78 million by 2050. Allocating 29 Mt/yr of CO_2 across 78 million people gives a ration of around 0.37 tonnes of CO_2 per person across the entire economy excluding aviation. This is a 95% reduction of CO_2 emissions compared to 2011 in order to meet the GHG commitments set out in the Climate Change Act.

6. There is thus no realistic way that the domestic sector can be heated with gas from fossil fuel sources without breaching the obligations of the Climate Change Act.

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[1] UK GHG emissions in 1990 were about 766 million tonnes CO2(e). The UK population in 2050 is expected to be 78 million. 1.8 tonnes per person reflects a national emission limit of 140 million tonnes CO2(e), or 18% of 1990 emissions.

[2] Note the difference between CO_2 emissions and CO_2(e) or CO_2 equivalent emissions.

[3] Adding 37.5 million tonnes non-CO_2 emissions from aviation to the accounts increases the baseline GHG emissions in 1990 by 37.5Mt, and also increases the allowance in 2050 - by 20% of 37.5 or 7.5 Mt a year. However because these 37.5 Mt of emissions will continue through 2050, the emissions from sectors other than aviation must be reduced by an extra 30 Mt (37.5-7.5).

ENERGY, POWER AND SEASONALITY

7. The average energy consumption for heating is much less than the peak power demands on cold days. In 2010 we used 440TWh[4] of heat from fossil fuels other than electricity to heat houses. If we heat for 6 months/year, and for 12 hours a day, we need about 200GW of electricity generating capacity to provide heating. On a cold day we need much more than the average, and 300GW seems a reasonable first approximation of the need to heat the existing housing stock. This compares with the total UK electricity generating capacity of 90GW.

8. The heat could be provided with heat pumps which deliver 2-4 units of heat for every unit of electricity used (*the Coefficient of Performance or COP*) provided they are installed in well designed systems. On cold days, with Air Source Heat Pumps, the COP will fall significantly, but let us assume an average COP of 3. Heating every home with a heat pump would reduce the additional electrical power demands from 300GW to about 100GW – still more than total UK generating capacity.

9. This ignores population growth. Population is projected to expand by 2050 to 78 million people. This will add another 7 million households – almost 30%. Even if these are all hyper-efficient dwellings the 100GW figure for domestic heating looks conservative.

10. Delivering 100GW of additional power would require substantial new low carbon generating capacity and probably a significant grid upgrade. However the seasonal nature of the demand means that the total energy required from this new generating capacity will be a fraction of its generating capacity.

11. Most low carbon technologies have low marginal costs of generation, and high capital costs. Nuclear power is a case in point; it could well provide significant levels of baseload power, but is completely unsuited to providing highly variable seasonal demand. Interconnection with Europe may allow a small amount of relief, but in general weather patterns are well correlated across Europe so power demands will also be correlated.

THE COST AND POTENTIAL OF ENERGY EFFICIENCY

12. Domestic energy efficiency clearly has a role to play. Even old houses can be refurbished to very high standards. However significant improvements in energy efficiency are expensive to carry out and difficult quality control. The Energy Savings Trust (EST) reports[5] the cost of the three simplest and most significant interventions for a typical house as being:

	Low estimate	High estimate
Loft Insulation (270mm)	£200	£700
Solid Wall insulation[6]	£5,500	£13,000
Double Glazing	£3,300	£6,500
TOTAL	**£9,000**	**£20,200**

[4] http://www.decc.gov.uk/assets/decc/11/stats/publications/dukes/5959-dukes-2012-annex-a.pdf . 2010 data show domestic energy consumption for all fuels except electricity and bio-energy of 37.7 million tonnes of oil equivalent – at 42GJ/TOE.

[5] http://www.energysavingtrust.org.uk/Using-this-site/Our-calculations

[6] Cavity wall insulation is ignored in this assessment as it makes savings that are insufficient to achieve anything close to the requirements – all houses will have to have additional insulation.

13. Assuming £15,000 per dwelling, and 26 million existing dwellings, the total cost will be of the order of £400 Billion. Given the 2050 target, this means expenditure of around £1Bn per month – around 1% of UK GDP.

14. Insulation alone it isn't enough to deliver the energy savings needed to avoid a massive reconstruction of the energy delivery system. A substantial proportion of heat is lost through air leakage, and making existing homes airtight is difficult. Then, once the home is airtight, air circulation and fresh air become problems. This more or less mandates mechanical ventilation with heat recovery – which in turn pushes the heating system to be driven by air source heat pumps. Delivering all of this means that homes need a major and expensive overhaul – it can't simply be done by piecemeal fitting.

15. A recent refurbishment of a 4-bedroom Victorian semi-detached house in Oxford to near zero carbon standards cost around £60,000 over and above the cost of meeting current building regulations. On the other hand, this home then reduced its total heating and hot water load to around 500W, with little variation summer and winter. If this level were to be achieved nationwide the total domestic heating load would be around 13GW – with much lower peaks and troughs than currently seen. This power demand could be met simply through savings in lighting and appliance efficiency.

16. Delivering these standards of energy efficiency requires a set of skills currently not present in either the professional or the construction community.

Discussion of Existing Policies and Measures

Measures supported by the RHI

Solid Biomass

17. The UK's total wood harvest in 2011 was around 10 million green tonnes. This is equivalent to around 25TWh, around 5% of the total heat load – even if it were all to be diverted from its existing uses to domestic heating. As other countries join the race to decarbonise, biomass imports will be seen as unsustainable.

18. Biomass boilers and biomass storage are too bulky for most homes, and the logistic challenges of moving biomass into urban areas is too great.

19. Furthermore, biomass may be zero carbon in the long term, but it is not zero carbon in the timeframe that is probably needed to avoid serious climate damage. Temperate and boreal trees will take 50 years to grow. Thus cutting down boreal forests will result in a large carbon emission pulse which is only slowly re-absorbed by replacement growth.

20. Thus solid biomass can only have a marginal impact on the problem of domestic heating.

Anaerobic Digestion

21. To generate enough gas for 440TWh requires around 150M tpy of dry maize or similar biomass. At a yield of 12 DMT/ha, this would require around 12 million ha – 4x the total area of arable crop in Britain. Add 20% to accommodate the increase in population and it is clear that gas from AD can, at best, be a marginal contributor..

Heat Pumps

22. Heat pumps can be categorised by their source of heat (air, ground, or water) and the way they distribute heat (warm air, wet heating system, and hot water

23. There are few dwellings with access to water that might make water source heat pumps viable. They can therefore only be marginal contributors at best.

24. Ground Source Heat Pumps (GSHPs) are typically installed with heat collected by near surface piping spread over a large area. This has the theoretical advantage that the temperature is near constant, and on cold days, well above the air temperature. However to avoid chilling the ground, large areas are needed per dwelling unless the dwelling is very highly insulated. Space is therefore a serious constraint for most dwellings. In addition capital costs are high and parasitic loads can be high, reducing the overall benefit.

25. Air Source Heat Pumps (ASHPs) are the easiest to install, and have the lowest capital costs. Most dwellings could install one. They will probably, therefore, form the basis of a low carbon domestic heating system and understanding them and how best to use and install them is critical.

26. ASHPs suffer from the disadvantage that their COP falls as air temperature falls – so doubling the heat load on a cold day can treble power demand. This will, if they are widely installed, increase the peakiness of national electricity demands during cold spells – exacerbating the problems of grid management and electricity generation. This can only be minimised by careful design of a dwelling, using extensive insulation, air tightness, and thermal mass.

27. Heat pumps operate best when the temperature difference between input and output is as low as possible. Most dwellings have wet heating systems designed for water flow temperatures of 60-70°C. At these temperatures the COP of heat pumps is low. Wet systems can run at 40°C, which increases the COP, but decreases the heat available to the dwelling. To compensate new radiators and pipes are generally needed.

28. The most efficient method of heat delivery using heat pumps is air circulation. This can be done at temperatures of around 25°C – thus maximising the COP. Air circulation is ideal for coupling with heat recovery. The exhaust air in such a system preheats the incoming cold air, and the cold side of the heat pump. With such a system, 80% of heat demand can be eliminated, but it relies on dwellings that are relatively air tight to prevent loss of warm air. Doing this is expensive but in a refurbished Victorian house[7] where this has been applied and monitored by Oxford University, power demanded for space heating has been reduced to around 500W, with almost no variation between summer and winter.

29. In contrast, anecdote suggests that homes which have heat pumps without the other design elements are expensive to run, and can perform less well from a consumer perspective than traditional heating systems. Heating installers therefore have little incentive to promote them.

30. The biggest single problem with the above retrofit was not technology, but skills. Neither architects nor builders knew how to design or execute the project. Furthermore, the current method of rating homes for energy efficiency takes no account of the issues of airtightness or heat recovery but negatively assesses the use of electricity for heating. The system penalises good energy design.

31. Thus, the really effective use of heat pumps requires a 'whole house' approach to energy – rather than a piecemeal approach of separating insulation, ventilation, and heating. In

[7] See www.myretrofit.blogspot.com

the absence of such an approach, which is not encouraged by the RHI, individual interventions may do more harm than good – by increasing the peakiness of power demand, increasing the costs of heating, creating a negative reputation for the technology, and reducing the value of homes that adopt such an approach by penalising them in the energy rating scheme.

THE GREEN DEAL

32. The Green Deal is fundamentally flawed in several ways.

33. The first failing is that the policy does not look forward at what might be needed by the UK housing stock to meet future needs. Instead it measures only whether the work done will reduce short term costs. Consequently all work that is done will be inadequate to meet the energy efficiency requirements in decades to come. It is almost certain therefore that everything installed under the Green Deal will have to be uninstalled and replaced with a higher specification.

34. There is no strategy for heat other than 'just a little less gas'. As a result there is no consideration of integrating heating, ventilation, heat recovery and insulation.

35. There is no objective way to ascertain the cost effectiveness of work done under the Green Deal, or even if it was done properly. This means a new house owner will acquire a financial liability with no guarantee of savings. House sales are already stressful, and adding the liabilities of additional loans will not make transactions easier. The result will be low uptake.

PROPOSALS FOR ACTION

36. Even if ASHPs are universally used, and IF all new dwellings are near-zero carbon, without massive investment in insulation, around 100GW of new carbon free generation will be needed, with no use for the power in the summer. The falling COP of heat pumps on cold days will boost power demand further – but not significantly increase annual energy sales. This makes the economics of baseload generators fraught. Delivering even the modest insulation improvements suggested by the EST will cost 1% of GDP each year for 35 years. Thus the scale of the problem is vast. It requires massive political will and financial resource to be directed towards solving the problem.

37. **No current combination of technologies and incentives will come remotely close to delivering the change needed in the domestic heating sector.**

RESEARCH NEEDS

38. **The key is research**. This needs to be co-ordinated acroross three broad themes; policy and economics, technology for houses, and technology for energy supply and storage. There is no body of work that examines in a coherent way the housing stock, the energy that it requires or could require, the technologies and costs needed to achieve viable efficiency improvements, and how the energy should be distributed. All these components interact, and there is no market mechanism that can deliver the strategic goal required. This means that government intervention is crucial.

RESEARCH AT THE HOUSE LEVEL

39. Houses today are, in essence, updated versions of the Anglo-Saxon hut. Houses of the future must become energy management machines – where the fabric of the house, the

appliances and control systems within it, and the heat and light, are managed actively to minimise both total energy use AND peak power demand.

40. Air tightness is critical to domestic heating performance; ventilation is critical to comfort and health. These two requirements work in opposing directions unless some form of mechanical ventilation is used with heat recovery. There seems to be no publicly available research correlating wind speeds and heating loads, though this data probably exists in the gas distribution industry. Nor is there data on the optimum level of air tightness (measured in air changes per hr at 50Pa) to enable effective heat recovery. Knowing this is critical to designing retrofit procedures to allow heating to be changed over to ASHP most cheaply.

41. What is needed is a serious reseach program focused on what the house of 2050 should look like, whether it be retrofit Victorian or 21st Century modern. Without this, all policy measures are likely to result in inefficient use of public funds to deliver poorly thought through and inadequate measures which do not deliver the goods.

RESEARCH AT THE ENERGY SUPPLY AND DISTRIBUTION LEVEL

42. Energy supply is about two separate requirements – total energy and peak power. Delivering peak power is likely to be much more difficult than delivering total energy.

43. A holistic, systems approach, is needed to understanding how heating in 2050 will be delivered. It clearly cannot be delivered by natural gas from fossil fuel sources, yet gas is the easiest fuel to store and the transport network is in place. It could be delivered by electricity, but the problems of peak power to average demand make the economics challenging and the distribution difficult. It is unlikely either that the public would sanction the number of new nuclear facilities needed to deliver with nuclear power if that was the preferred option.

44. New technologies, ranging from 'electricity to gas' (converting summer excess into a stored winter fuel), hydrogen to provide peak power generation, phase change materials to reduce peak heating loads (or to manage down cooling loads at peak demand times), smart grids to manage demand generally all need to be researched. The research cannot reside in separate silos. All these interact with each other, and need to be developed as **an integrated energy system unlike anything we have ever seen before.**

45. There is no market mechanism capable of stimulating this. Nor will minor incentives create the stimulus for other than piecemeal attacks on the problem. Once again it requires a national co-ordinated effort with clear funding and commitment.

46. It should also be noted that the only renewable resource that correlates well with heat demand is wind. Analysis is needed of the relationship between heat demand and wind generation to establish if wind has a greater strategic role going forwards.

RESEARCH AT THE THE POLICY AND ECONOMICS LEVEL

47. Any proposed solution will demand a massive share of national resources, and have substantial long term impacts on both state and personal finances. It could also have social and economic benefits – energy bills will fall, and improving the housing stock cannot be exported to a low cost country. The technology options therefore need to be accompanied by the policy and economic frameworks that make them practical.

48. One major problem is the sheer disruption to lives and homes from implementing such major changes (think about the challenge of clearing a loft). This will inhibit actions that may be economically very attractive. This needs addressing.

POLICY NEEDS

49. New homes need to be built to the standards that will pertain in 2050. Currently they are being built with the presumption that the energy system of 2050 will be much like that of today. This is clearly not true, and will result in a major ugrade cost.

50. There are grossly insufficient skills in the economy to carry out the scale of changes needed if 750,000 dwellings are to be upgraded every year between now and 2050. This means extensive training is needed, of both professionals and constructors. Building control and inspection – already weak, need massive uprating to cope.

51. The supply chain for equipment and materials for ultra-energy efficient homes is lacking.

52. One way to develop the skills and the supply chain, and the consumer accceptability of energy efficient housing, is to stimulate early adopters with fiscal breaks. For example, making the first 1 million homes (new or retrofit) that meet **a high and objective** standard (such as Passivhaus) eligible for mortgage interest relief. This would have little cost to the Treasury, as it will stimulate economic activity that otherwise would not have happened, and create a highly desirable feature for home owners who sell (unlike the Green Deal that creates a liability).

53. By the time the 1 million homes had been built or converted the training and supply chain issues will have moved forwards massively.

54. A further policy challenge lies in council planning approval. The UK housing stock was built largely when family sizes were different, the population was much smaller, the emphasis on design and efficiency was non-existent, and pressures to constrain development on greenfield sites were equally non-existent. New energy efficient homes using modern materials and able to accommodate the increasing population without increasing land take need councils to be much more accepting of novelty, experimentation, and reconstruction of our streetscape. A presumption in favour of planning for ultra-energy efficient homes would go a considerable distance towards overcomeing this unneccessary roadblock.

55. Finally, the scale of transformation is so great, and the lifetime of the infrastructure assets involved so long, that urgent action is needed to have any chance of delivering a successful outcome by 2050.

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