ENERGY UK

A response to the 2007 Energy White Paper

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Executive summary

It is now widely accepted that human-induced climate change is real, that global temperatures may spiral out of control, and that deep cuts are needed urgently in emissions of CO_2 and other greenhouse gases.

Many people now see climate change as at least as big a threat as war but, so far, the Government's response has not matched the challenge. There is a need for a much greater sense of urgency and for more joined-up thinking, to establish coherent and effective policies that will halt the rise in UK emissions of greenhouse gases and start to bring them down.

It is true that UK emissions are dwarfed by emissions from other countries but unless the UK can put its own house in order, it will have little credibility in international negotiations.

This report about how the UK may contribute to solving the problem of climate change is, in effect, a commentary on the Government's current proposals for future energy supplies and reductions in CO_2 emissions as described in the Government's Energy Review (DBERR2006) and Energy White Paper (DBERR2007). Although there is a need to reduce emissions of all greenhouse gases, the report concentrates mainly on the problem of reducing emissions of CO_2.

Incentives

To a large extent, the problem of cutting CO_2 emissions is a problem of providing the right framework of incentives for people and organisations, especially financial incentives, so that everyone has a substantial reason for "doing the right thing".

Carbon rationing

Some progress can be made via exhortation, carbon taxes, and systems of tax breaks and grants, but incentives to cut CO_2 emissions will not be put on a sound footing without a system of carbon rationing, including Tradable Personal Carbon Allowances (PCAs).

PCAs should prove much more popular than green taxes because many people with smaller incomes will have surplus allowances that they can sell for cash.

Although carbon rationing should provide the main framework of incentives, there may be a need for other schemes, such as feed-in tariffs, in particular cases.

The Climate Change Bill

The Climate Change Bill (DEFRA2007) is intended to put a legal obligation on the Government to bring down UK emissions of CO_2 by at least 3% each year. But in its current form, it is too weak:

- At least 90% cuts in carbon dioxide emissions are needed by 2050, not the 60% cut currently envisaged.[1]
- There should be an annual budget for CO_2, not a five-year budget as suggested by the Government.

[1] In his recent speech to the Labour Party Conference, Gordon Brown has indicated that targets for CO_2 reductions in the Climate Change Bill should be higher. This is welcome.

- Aviation and shipping *must* be included within the scope of the Bill.
- The carbon footprint of all goods and services imported from abroad should count as part of the UK's emissions.
- The UK should not be allowed to meet its targets by buying 'carbon offsets' from abroad. There is far too much scope for schemes that are either futile (yielding no net cuts in CO_2 emissions) or simply fraudulent.
- The system should be administered by an independent body composed of people appointed for their technical competence, not representatives of 'stakeholder' groups.

Zero-carbon eco-renovation

It is inconceivable that we would tear down the entire UK stock of buildings and replace them with zero-carbon buildings. And relying on the normal replacement rate would be far too slow. So there is a need for a vigorous programme to upgrade existing buildings, aiming to reduce their emissions to zero or nearly so. There is a need for *Zero-Carbon Eco-Renovation Demonstrators*, showing how this can be done with different types of building.

Since most buildings are heated by gas, a programme of zero-carbon eco-renovation should go a long way towards reducing UK consumption of gas and should reduce the need to import gas from abroad.

Generation and conservation of electricity

In the Energy White Paper (DBERR2007), disproportionate attention has been given to Carbon Capture and Storage (CCS) and to nuclear power and too little attention has been given to realising the huge potential of renewable sources of electricity and conservation of electricity.

Together, renewable sources with conservation of electricity can easily meet all current and anticipated future UK demands for electricity. With few exceptions, they are at or very close to the stage of development where they can be applied in practice.

With the provision of facilities to match variable supplies of electricity to variable demands, sources of clean energy such as wind power may be expanded well beyond the limits imposed by conventional wisdom. Zero-carbon eco-renovation can be part of a three-way strategy to plug any possible "energy gap" and ensure the resilience of UK electricity supplies.

We don't need nuclear power

Nuclear power is one of the worst of all methods for generating electricity. Fortunately, there is now abundant evidence from several different reports that the UK can make deep cuts in CO_2 emissions from electricity generation and meet its current and anticipated future needs for electricity, without using nuclear power.

If nuclear power was much cheaper than the alternatives, we might need to consider using it. But the weight of evidence is that, when all the hidden costs are added in, nuclear power is one of the most expensive sources of electricity. If nuclear power provided greater security of supplies than the alternatives, we might need to consider using it. But the evidence points in the other direction.

Concentrating solar power and the DESERTEC concept

The 'DESERTEC' concept is an important 'vision' for future energy supplies and other benefits in Europe, the Middle East and North Africa (EUMENA) developed by the 'TREC' group of scientists and engineers (see www.trec-uk.org.uk, MCSP2005 and TCSP2006). Concentrating solar power (CSP) is *already* feeding electricity into the European transmission grid. With the right political impetus, CSP could begin to supply the UK market within 5 years.

In collaboration with other countries throughout EUMENA, steps should be taken to make the DESERTEC vision a reality.

A EUMENA-wide Supergrid and a single market for electricity

Large-scale HVDC transmission grids, designed to operate in conjunction with existing HVAC grids, have important benefits, especially with renewable sources of electricity.

If these kinds of large-scale grids are to operate to their full potential, then it is essential that unnecessary restrictions on the transfer or trading of electricity should be removed. There should be a single market for electricity throughout EUMENA (as in the UK) and the creation of a single market within Europe would be a very useful staging-post in that development.

Given the major advantages and modest cost of establishing a EUMENA-wide or Europe-wide Supergrid and a single market for electricity, it would be good to see these things put in place as soon as possible.

Transport

Public transport by buses and trains is generally much more fuel-efficient than cars and should be encouraged. Walking and cycling should also be encouraged. In particular, there is a pressing need for a comprehensive nation-wide network of traffic-free routes for walkers and cyclists, to bring things up to the standards that have been enjoyed for many years in countries like Germany and Holland.

Bio-fuels derived from waste biomass are quite acceptable and there is some scope for bio-fuels derived from plants that are grown for the purpose, especially if the whole plant can be used. But, beyond that, there are risks that bio-fuels may displace food production and accelerate destruction of rain forest.

There is potential for the creation of synthetic fuels using the enormous quantities of solar energy falling on desert regions.

Given the great potential that exists for generating electricity from renewable sources, there is great scope for the use of electricity in powering trains and road vehicles. To replace fossil fuels in overland transport with renewable electricity would require less than 50% more electricity than we currently use.

The scope for significant reductions in CO_2 emissions from planes is very limited. There is certainly no case for expanding UK facilities for air travel.

Wind has been the main source of power for shipping for thousands of years and it can be so again. But now there is great scope for the use of modern technologies to make it more efficient and less labour-intensive than before.

1 Introduction

It is now widely accepted that human-induced climate change is real, that global temperatures may spiral out of control, and that deep cuts are needed urgently in emissions of CO_2 and other greenhouse gases.[2]

It is true that UK emissions are dwarfed by emissions from other countries but unless the UK can put its own house in order, it will have little credibility in international negotiations.

This report about the UK's contribution to solving this problem is, in effect, a commentary on the Government's current proposals for future energy supplies and reductions in CO_2 emissions as described in the Government's Energy Review (DBERR2006) and Energy White Paper (DBERR2007).

The report has been prepared under the banner of FGHTGH,[3] an environmental think tank and campaigning group. It has benefited from research and thinking since 2001 in the development of the FGHTGH website at www.mng.org.uk/gh/. It has also benefited from many discussions, both face-to-face and online, with other people concerned about climate change and energy supplies and I am grateful for many insights and points of information that I have gained in that way.

I have said relatively little about areas where I am broadly in agreement with the Government and have paid most attention to what I see as omissions or errors in what the Government is saying and doing. These points have been highlighted in the report.

The report focuses mainly on what the UK should do but it takes account of the fact that some solutions work best on a larger scale, across Europe or beyond. Although there is a pressing need to reduce emissions of *all* greenhouse gases, the report concentrates mainly on how to reduce emissions of CO_2.

1.1 Climate change as big a threat as war

Although Tony Blair has spoken often about the need for action on climate change, UK emissions of CO_2 are higher now than in 1997 when his government first came in to power, and they are continuing to rise. While I agree with much of what is said in the 2006 Energy Review (DBERR2006) and the 2007 Energy White Paper (DBERR2007), I believe they contain significant weaknesses, and I see a mismatch between what the Government says and what it does.

Ban Ki-moon, Secretary General of the UN, has said that "… the danger posed by war to all of humanity and to our planet is at least matched by the climate crisis and global warming."[4] James Hansen and others writing in the *Philosophical Transactions of the Royal Society A* (RS2007) say "Recent greenhouse gas emissions place the Earth perilously close to dramatic climate change that could run out of control, with great dangers for humans and other creatures."[5]

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[2] The potentially disruptive effects of 'peak oil' (when demand for fossil fuels outstrips supply) and concerns about the security of energy supplies are other good reasons for decarbonising the world's economy.
[3] FGHTGH is short for "**From Greenhouse to Green House**".
[4] "UN chief warns on climate change", BBC News, 2007-03-02, http://news.bbc.co.uk/2/hi/in_depth/6410305.stm .
[5] See also "The Earth today stands in imminent peril", The Independent, 2007-06-19, http://environment.independent.co.uk/climate_change/article2675747.ece .

If climate change is indeed as big a threat as Ban Ki-moon has said, and many people now believe that it is, meeting this threat should be treated as if we were fighting a major war.

There is a need for a much greater sense of urgency and for more joined-up thinking, to establish coherent and effective policies that will halt the rise in UK emissions of CO_2 and start to bring them down.

2 Incentives

To a large extent, the problem of cutting CO_2 emissions is a problem of providing the right framework of incentives for people and organisations, especially financial incentives, so that everyone has a substantial reason for "doing the right thing."

2.1 Carbon rationing

Some progress can be made via exhortation, carbon taxes, and systems of tax breaks and grants, but I believe that incentives to cut CO_2 emissions will not be put on a sound footing without a system of carbon rationing. In particular, we need as system of "Domestic Tradable Quotas" or "Personal Carbon Allowances" (PCAs),[6,7,8,9,10,11,12,13,14] as discussed in Appendix 1.

In brief, a PCA scheme means a carbon ration for each person, very much like the rationing 'points' that were issued for food and other necessities during World War II but with the difference that people can sell surplus allowances for cash.

A properly-administered system of PCAs should prove to be much less of a political hot potato than raising green taxes. This is because many people, mainly those with small incomes, will have surplus allowances that they can sell for cash.

I disagree profoundly with the Government's view that "the current system of taxation strikes the right balance between protecting the environment, protecting the most vulnerable in society and maintaining sound public finances." (DBERR2007, pp 61-62) but welcome the Government's willingness to continue studying PCAs.[15]

A properly-administered system of carbon rationing, including PCAs, is essential if the UK is to begin making the decisive cuts in CO_2 emissions that are needed.

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[6] David Miliband MP, Secretary of State for Environment, Food and Rural Affairs, made a speech about personal carbon allowances on 2006-07-19: http://www.defra.gov.uk/corporate/ministers/speeches/david-miliband/dm060719.htm .

[7] There is a page about 'personal carbon trading' at the Environmental Change Institute, Oxford University: http://www.eci.ox.ac.uk/research/energy/pct-more.php .

[8] ML2006, http://www.newstatesman.com/200610230015 .

[9] MH2004. This is the most important account of the reasons why PCAs are needed: essential reading for anyone with an interest in the subject.

[10] Tradable Energy Quotas by David Flemming, http://www.teqs.net/ .

[11] RSKA2004, http://www.mng.org.uk/gh/mechanisms/brilliant_ideas/tradable_quotas.htm .

[12] SRJT2006, http://www.mng.org.uk/gh/resources/DEFRA_carbon_trading_2006.pdf .

[13] Carbon Rationing Action Groups (CRAGS), http://www.carbonrationing.org.uk/what .

[14] Carbon Limited, exploring carbon trading, http://www.rsacarbonlimited.org.uk/ .

[15] What the quoted passage fails to recognise is that, given the huge risks that now confront us, protecting the environment is not a matter for compromise between competing interests. As Mark Lynas has said, "you can't negotiate with the planet". Reductions in CO_2 emissions must be determined by the best available scientific advice, without any kind of negotiation or compromise. And carbon rationing is the only way to ensure that reductions in emissions do conform to scientific advice.

2.2 Other incentives

Although carbon rationing would provide the overall framework of incentives to reduce CO_2 emissions, there may also be a need for other incentives in particular cases. A system of feed-in tariffs has proved to be very successful in Germany in encouraging the uptake of renewable sources of energy[16] and there may be a case for a similar scheme in the UK.

2.3 The Climate Change Bill

The Climate Change Bill (DEFRA2007) is intended to put a legal obligation on the Government to bring down UK emissions of CO_2 by at least 3% each year. The Government's inclusion of the Climate Change Bill in the Queen's Speech of November 2006 and its declared support for the Bill in DBERR2007, para 5.1.33, are very welcome. But *the Bill is in danger of being watered down, reducing the incentives for governments of any colour to make meaningful cuts in UK emissions*. Details of these concerns are in Appendix 2.

3 Zero-carbon eco-renovation

I agree with much of what the Government has to say about saving energy but there are some specific areas where I would like to see more action.

The government's proposal for "future changes to Building Regulations such that by 2016, all new homes built in England will have to be zero carbon." (DBERR2007, para 2.104) is very welcome but *far more attention should be given to upgrading existing buildings with much more ambitious targets than have currently been set*.

Housing accounts for about 28% of UK emissions of CO_2.[17] If we include non-residential buildings as well, the proportion is even higher. *But it is inconceivable that we would tear down the entire UK stock of buildings and replace them with zero-carbon buildings. And relying on the normal replacement rate would be far too slow.* Consequently, there is a need for a vigorous programme to upgrade existing buildings, aiming to reduce their emissions to zero or nearly so.

There is much more potential for zero-carbon eco-renovation than has so far been recognised.

More detail, with specific recommendations for *Zero-Carbon Eco-Renovation Demonstrators* and changes in planning law are described in Appendix 4.

Since most buildings in the UK are heated with gas, a programme of zero-carbon eco-renovation can go a long way to reducing UK consumption of gas and can reduce the need to import supplies of gas from abroad.

Zero-carbon eco-renovation may be part of a three-way strategy to plug any possible "energy gap" and increase the resilience of UK electricity supplies (Section 4.5).

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[16] "No policies, no cash. The result: missed targets", Ashley Seager and Mark Milner, The Guardian, 2007-08-13, http://www.guardian.co.uk/environment/2007/aug/13/renewableenergy.climatechange .
[17] "Carbon dioxide emissions by end user: 1970-2004", DEFRA, http://www.defra.gov.uk/environment/statistics/globatmos/kf/gakf07.htm .

4 Generation and conservation of electricity

Electricity is, of course, not the only form of energy that we use but the generation of electricity currently accounts for about 25% of UK emissions of CO_2[18] and it is important that those emissions are cut as soon as possible.

In Government policies and actions, and in the Energy White Paper (DBERR2007), *disproportionate attention has been given to Carbon Capture and Storage (CCS) and to nuclear power and that far too little attention has been given to realising the huge potential of renewable sources of electricity*.

On the 9th of March 2007, the European Union agreed to obtain 20% of its energy from renewable sources by 2020.[19] Since this agreement covers all forms of energy, not just electricity, and since electricity is where the biggest potential for renewable energy lies, an even larger proportion of electricity—perhaps as much as 35%—must come from renewable sources by 2020. *If the UK is to honour its share of this commitment, it will need to be much more active in removing obstacles and creating the right incentives to bring renewable sources of electricity on stream*.[20]

4.1 We don't need nuclear power

Since nuclear power is, by a wide margin, the worst of all methods for generating electricity (see HC2006 and Appendix 3), we should avoid it unless there is no alternative. Fortunately, there is now abundant evidence from several different reports (GM2006, MB2006, TC2006A, GP2006, TCSP2006, FOE2006, NEF2005, SDC2005) that the UK can make deep cuts in CO_2 emissions from electricity generation and meet its current and anticipated future needs for electricity, without using nuclear power.[21] There is corroboration in some of the subsections below.

If nuclear power was much cheaper than the alternatives, we might need to consider using it. But the weight of evidence is that, when all the hidden costs are added in, it is one of the most expensive sources of electricity (see Appendix 3). This relative disadvantage of nuclear power is likely to increase as the costs of renewable sources of energy are brought down by economies of scale and refinements in technologies.

If nuclear power provided greater security of supplies than the alternatives, we might need to consider using it. But the evidence points in the other direction. Contrary to what Malcolm Wicks MP has said, nuclear power is not a "home grown" source of power: all nuclear fuels are imported into the UK. The vulnerability of nuclear plants and nuclear transports to terrorist attack has implications for security of supplies.

In the non-nuclear low-carbon scenarios described in the TRANS-CSP report from the German Aerospace Centre (TCSP2006), there is an overall *reduction* in imports of

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[18] The website of the UK Office for National Statistics says "Greenhouse gas emissions from electricity generation constituted 25.4 per cent of all greenhouse gas emissions in 2003 …" (http://www.statistics.gov.uk/cci/nugget.asp?id=901). Most of those emissions are probably CO_2.

[19] "EU agrees deal to reduce carbon emissions by 20%", The Guardian, 2007-03-09, http://environment.guardian.co.uk/energy/story/0,,2030146,00.html .

[20] Although special arrangements have been negotiated to take account of France's current reliance on nuclear power, that technology cannot, by any stretch of the imagination be classified as 'renewable', and neither can CCS. If the UK is to honour its commitments, about 35% of the UK's electricity must come from truly renewable sources by 2020.

[21] Details of the reports that have been referenced, and other reports about decarbonising the world's economy without using nuclear power, with links for downloading, may be found at http://www.mng.org.uk/gh/scenarios.htm .

energy into Europe (including the UK) compared with the situation now, an overall *increase* in the diversity of sources of electricity, and a corresponding *increase* in the resilience and security of electricity supplies.

If nuclear power could be introduced more quickly than the alternatives, we might need to consider using it. But nuclear power has much longer lead times than most renewable sources of electricity and it is notorious for overruns in building times (and costs).

4.2 Remove hidden subsidies for nuclear power

Lord Truscott, Parliamentary Under Secretary of State for Energy, has said there will be no subsidy, levy, nuclear obligation or market intervention to help launch a new nuclear programme.[22] But there are massive subsidies for the nuclear industry, although they are disguised and not obvious at first sight. Here are three examples:

- Throughout the world, the nuclear industry pays only a small fraction of the cost of insuring fully against the costs of a Chernobyl-style accident or worse. Details are given in Appendix 3.
- The public is being made to carry the risk, and the corresponding costs, that arise from allowing the nuclear industry to carry nuclear waste and nuclear fuel on trains throughout the UK (see Appendix 3). This is another large subsidy for the industry.
- Future generations are being made to pay for the costs arising from nuclear waste that will be dangerous for thousands of years. This represents a very large subsidy from those people, yet to be born, to the nuclear industry of today.

Before any plans are made to build new nuclear power stations in the UK, all hidden subsidies for nuclear power must be removed, and the problem of long-lived nuclear waste must be solved.

4.3 Renewable sources of electricity and conservation of electricity

For many years, renewable sources of electricity and conservation of electricity have been regarded as being good in theory but not practical or "serious," and I believe that the Government is still influenced by this backward-looking thinking. Despite the huge potential for renewable energy in the UK, our record is poor compared with countries like Germany and Denmark.[23]

Compared with the large amounts of investment and research that have, over many years, been lavished on the generation of electricity from fossil fuels and nuclear power, renewable sources of electricity have received very little support.[24,25] The Government should not be shy in providing whatever support is needed to bring these

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[22] "Britain gets nuclear waste warning from energy chiefs", The Independent, 2007-03-02, http://news.independent.co.uk/business/news/article2318799.ece .

[23] See "Revealed: cover-up plan on energy target", Ashley Seager and Mark Milner, The Guardian, 2007-08-13, http://www.guardian.co.uk/environment/2007/aug/13/renewableenergy.energy. See also "The irony of US and UK renewable policies", Craig Morris, Renewable Energy Access, 2007-06-25, http://www.renewableenergyaccess.com/rea/news/reinsider/story?id=49084 .

[24] See "Blow, blow thou winter wind", Andrew Simms, The New Statesman, 2004-06-28, http://www.newstatesman.com/200406280016 .

[25] See "Nuclear power 'stings' tax payers", BBC News, 2006-06-20, http://news.bbc.co.uk/1/hi/uk_politics/5097434.stm .

technologies on stream quickly, and to bring prices down via economies of scale and refinements in their design and manufacture.

A range of low-carbon sources of electricity and methods for reducing wastage of electricity are reviewed in Appendix 5. Together, they can meet all current and anticipated future UK demands for electricity, and more. With few exceptions, they are at or very close to the stage of development where they can be applied in practice.

A greater commitment to these renewable technologies is needed, removing unnecessary obstacles and providing the right framework of incentives to ensure that they are implemented as soon as possible.

It is not normally a good idea for governments to try to pick winners amongst different technologies but they should provide support for new low-carbon technologies until they can get established. Currently, there appear to be some biases in what the Government says and does:

- The emphasis placed on **combined heat and power** in the recent White Paper (DBERR2007) is welcome but there is still a gap between words and actions. A recent application by E.ON to build a new coal-fired power station at Kingsnorth is being considered despite the fact that it does not make proper provision for combined heat and power.[26] *Any such application should be ruled out automatically*.
- **Tidal lagoons** have several advantages over the proposed Severn barrage (see Appendix 5) but they are not mentioned at all in the White Paper (DBERR2007). By contrast, the Severn barrage is mentioned four times.
- The huge potential of **concentrating solar power** and **the DESERTEC proposals** (Section 5) receives no mention in the White Paper (DBERR2007).
- Since fusion nuclear power is at least 30 years into the future (DBERR2007, pp 223-224), money spent on research into this pipe dream would be much better spent on technologies that can deliver clean energy *now*.

4.4 Matching supplies to demand

All sources of electricity are variable and the demand for electricity varies from minute to minute. Consequently, there is a need for mechanisms that will allow power engineers to match supplies to demand. In general, this can be done by providing some combination of the following: 1) spare generating capacity; 2) 'peaking power': sources of electricity that can respond quickly to peaks in demand; 3) methods for storing power; 4) methods for managing demand; 5) large-scale transmission grids. The first four of these are discussed Appendix 7 and the last is discussed in Section 6.

With appropriate provision of facilities like these, wasteful and polluting practices such as maintaining power stations on 'spinning reserve' may be largely eliminated, and sources of clean energy such as wind power may be expanded well beyond the limits imposed by conventional wisdom.

4.5 Plugging the energy gap

It is said that the closure of nuclear power stations and coal-fired power stations as they reach the end of their lives will leave Britain with an "energy gap" or shortfall in

[26] See http://www.greenpeace.org.uk/blog/climate/say-no-to-new-coal-20070531 .

generating capacity.[27] This, coupled with possible worries about the UK becoming unduly dependent on imports of gas from possibly unreliable sources such as Russia, has been used to justify giving the go-ahead for a new generation of nuclear power stations (DBERR2007) and giving permission for the building of a new coal-fired power station at Kingsnorth in Kent.[28]

The building of new nuclear power stations would be too slow to bridge any possible "energy gap" and there are in any case much better ways of maintaining supplies of electricity in the UK:

- With the right framework of incentives, renewable sources of energy can be ramped up to the levels already achieved in countries like Germany, or beyond (Section 4.3). For example, it has been estimated that tidal streams in the Pentland Firth could generate up to a quarter of the UK's electricity using underwater turbines that are relatively simple and relatively quick to install.[29]
- Because gas is the dominant fuel used for space heating and water heating in the UK, a vigorous programme of zero-carbon eco-renovation of buildings (Section 3) would produce substantial reductions in the UK demand for gas. Some of the gas that is saved may be used to provide backup supplies of electricity that can respond quickly to peaks in demand (Section 4.4). In 2006, 310,355 GWh of gas were used for the generation of electricity and 364,555 GWh was domestic consumption (DBERR2007a). Since most of the latter would be for space heating and at least half of that may be saved by eco-renovation, it is clear that a large amount of gas may be freed up for use in the generation of electricity.
- The use of combined heat and power can raise the overall efficiency of a gas-fired power station from about 48% to more than 70%,[30] thus making much better use of the gas that is used. CHP has the additional advantage that it may be used right across the range of scales, including small domestic units.[31]

In summary, a three-way strategy—ramping up renewables, a vigorous programme of zero-carbon eco-renovation of buildings to release gas that may be used to supply peaking power (Section 4.4), and expanding CHP—will enable the UK to make deep cuts in CO_2 emissions and help to ensure the resilience of electricity supplies at the same time.

5 Concentrating solar power and the DESERTEC concept

The 'DESERTEC' concept is an important 'vision' for future energy supplies and other benefits in Europe, the Middle East and North Africa (EUMENA) developed by the 'TREC' group of scientists and engineers.[32] The main elements of the concept are these:

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[27] "Britain facing large energy gap", BBC News, 2005-11-09, http://news.bbc.co.uk/1/hi/sci/tech/4423456.stm .
[28] Personal communication from Albert Owen MP, a member of the Energy Bill Committee.
[29] "The rise of British sea power" (The Independent, 2008-03-23, http://www.independent.co.uk/environment/green-living/the-rise-of-british-sea-power-799630.html).
[30] CHP FAQ of the Combined Heat & Power Association, http://www.chpa.co.uk/.
[31] See http://www.whispergen.com/main/PRODUCTS/.
[32] The "Trans-Mediterranean Renewable Energy Cooperation", an initiative of the Club of Rome, is a group of scientists and engineers developing a collaboration amongst countries in Europe, the Middle East and North Africa (EUMENA) to take advantage of the truly enormous quantities of energy falling as sunlight on the world's hot deserts—and wind energy in those regions too. Further information may be found at http://www.trecers.net/index.html and http://www.trec-uk.org.uk/index.htm .

- Deep cuts in CO_2 emissions from electricity generation throughout EUMENA using a wide variety of low-carbon sources of energy, with a phase-out of nuclear power.
- An important part of the energy mix is carbon-free electricity from areas of hot desert, taking advantage of the truly enormous quantities of solar energy in those regions and the proven technology of 'concentrating solar power' (CSP).[33,34]
- Transmission of renewable electricity throughout EUMENA via a 'supergrid' of highly-efficient 'HVDC' transmission lines. Such a grid has other advantages outlined in Section 6 and Appendix 6. Even without the supergrid, it is technically feasible for the UK to begin to import solar electricity from desert regions via the existing transmission network.[35]
- For a variety of reasons, there would be enhanced security of energy supplies.[36]
- There is potential to use solar energy from desert regions to power industrial processes and to create synthetic fuels.
- Additional benefits including:
    - Desalination of sea water using waste heat from CSP plants—a valuable bonus in arid regions.
    - Shaded areas under the mirrors of CSP plants are protected from the full glare of harsh tropical sunlight and may be used for many purposes, including horticulture using desalinated sea water.
    - Jobs and earnings throughout EUMENA.
    - Global security:
        - Reduced risks of conflict over shortages of energy, water, food and usable land.
        - Collaboration amongst countries of EUMENA, with substantial benefits for all, can help to reduce tensions, improve relations and build understandings amongst different groups of people—a positive alternative to the confrontational policies of recent years.

Concentrating solar power (CSP) is *already* feeding electricity into the European transmission grid.[37] With the right political impetus to create a single European market for electricity and remove unnecessary obstacles, CSP could begin to supply the UK market within 5 years. CSP plants are quick to build and capacity may be ramped up fast.

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[33] CSP is the simple but effective technique of using mirrors to concentrate sunlight to create heat which is used to raise steam to drive turbines and generators, just like a conventional power station. An overview of CSP, with links to other sources of information is at http://www.trec-uk.org.uk/csp.htm .
[34] In the scenario up to 2050 described in the TRANS-CSP report (TCSP2006), it is envisaged that CSP would provide no more than 15% of Europe's electricity supplies.
[35] See http://www.trec-uk.org.uk/elec_eng/cascade.html.
[36] Some of the reasons are summarised in http://www.trec-uk.org.uk/csp_sections/csp_security.htm .
[37] "PS10 solar power tower", Wikipedia, http://en.wikipedia.org/wiki/PS10_solar_power_tower.

The DESERTEC concept has been developed with considerable professionalism and care in the 'MED-CSP' and 'TRANS-CSP' reports from the German Aerospace Centre (MCSP2005 and TCSP2006).[38]

Given the potential of these proposals, there is a need for governments throughout EUMENA to collaborate to remove unnecessary obstacles and smooth the path for their realisation.

6 A EUMENA-wide Supergrid and a single market for electricity

For reasons outlined in Appendix 6, large-scale HVDC transmission grids, designed to operate in conjunction with existing HVAC grids, have important benefits, especially with renewable sources of electricity. Despite these benefits and despite the fact that HVDC technology has been in use for over 50 years, there is no mention of large-scale HVDC grids anywhere in the White Paper (DBERR2007).

There are good reasons for the European Union to invest in a European Supergrid as proposed by Airtricity (AT2006) and it would be even better if a large-scale HVDC grid could be established, spanning the whole of EUMENA,[39] as proposed by the TREC group (Section 5) and detailed in TCSP2006 and FTHM2007.

6.1 A single market for electricity

If large-scale HVDC grids are to operate to their full potential, then it is essential that unnecessary restrictions on the transfer or trading of electricity should be removed. There should be a single market for electricity throughout EUMENA (as in the UK) and the creation of a single market within Europe would be a very useful staging-post in that development.

Accordingly, I very much welcome the Government's statement that "Recognising our increased reliance on global energy markets, we are committed to a strong international agenda to promote more open and competitive markets overseas. We will work towards realising fully liberalised European markets by 2010 and work with the European Union to extend the application of market principles beyond its boundaries …." (DBERR2006, para. 10.25).

HVDC grids and a single market for electricity are really complementary: a single market is needed if the grids are to reach there full potential but the reverse is also true. Over wide area like Europe or EUMENA, a single market cannot operate effectively without an HVDC transmission grid.

6.2 Costs

In TCSP2006 and FTHM2007 it is proposed that, throughout EUMENA, there should be an HVDC grid of 20 power lines, each one of 5 GW capacity. Two such lines between North Africa and the UK would provide 10 GW of capacity—a useful contribution to UK electricity supplies.

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[38] Further information may be found at http://www.trec-uk.org.uk/index.htm and http://www.trecers.net/index.html .

[39] "Europe, the Middle East and North Africa".

The cost of two 5 GW lines like that has been estimated to be about €5bn (FTHM2007). The estimated cost of the full 100 GW EUMENA-wide transmission grid is €45bn (*ibid.*).

These costs may seem large but they would be spread over a few years. They compare quite favourably with other things that governments spend money on:

- The estimated cost of widening the M1 motorway is €7.6bn (£5.1bn).[40,41]
- Gordon Brown has said that the cost of cleaning up Britain's nuclear legacy is likely to be €133.4bn (£90bn).[42]
- Worldwide, annual subsidies for fossil fuels amount to about €167bn ($235bn).[43]

6.3 Conclusion on electricity transmission and trading

Given the major advantages and modest cost of establishing a EUMENA-wide or Europe-wide Supergrid and a single market for electricity, these things should be put in place as soon as possible.

7 Transport

At present, transport by road vehicles, trains, ships and planes relies almost entirely on fossil fuels and is a major source of CO_2 emissions. This section briefly reviews some of the options for decarbonising transport and makes some recommendations.

7.1 Public transport, bikes and feet

Public transport by buses and trains is generally much more fuel-efficient than cars and should be encouraged.

Walking and cycling should also be encouraged. In particular, *there is a pressing need for a comprehensive nation-wide network of traffic-free routes for walkers and cyclists, to bring things up to the standards that have been enjoyed for many years in countries like Germany and Holland*. The Sustrans charity[44] is building a national network but this important work would be greatly accelerated if a small portion of the £13bn that the Government is spending on roads[45] were transferred to the building of traffic-free routes for walkers and cyclists.

7.2 Bio-fuels

Bio-fuels derived from waste biomass (e.g., waste cooking oil) are acceptable and there is some scope for bio-fuels derived from plants that are grown for the purpose, especially if

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[40] "M1 widening to cost £21m per mile", The Observer, 2007-05-06, http://observer.guardian.co.uk/uk_news/story/0,,2073611,00.html .

[41] Given the urgency of the need to cut UK emissions of CO_2, widening the M1 is entirely the wrong thing to do. Road traffic is currently a major source of CO_2. Unless or until there is new technology for low-carbon or zero-carbon road transport (and the Government does not seem to have any grip on this problem), we cannot cut emissions from road transport without reducing the volume of traffic.

[42] "Nuclear costs to hit £90bn, warns Brown", The Observer, 2006-06-04, http://observer.guardian.co.uk/business/story/0,,1789671,00.html .

[43] "Fossil fuel subsidies 'must end'", BBC News, 2004-06-21, http://news.bbc.co.uk/2/hi/science/nature/3818995.stm.

[44] See http://www.sustrans.org.uk/.

[45] "Labour's 'stealth' road schemes", The Sunday Times, 2007-04-08, http://www.timesonline.co.uk/tol/news/uk/article1626730.ece .

the whole plant can be used. But, as is noted in Appendix 5, there is a risk that large-scale expansion of bio-fuels would lead to rising costs for food with a corresponding risk of malnutrition or even starvation, and there is also a danger that rainforest and other important habitats would be destroyed.

7.3 Synthetic fuels

Given the enormous quantities of energy that fall as sunlight on desert regions and given that it is possible to tap into this cornucopia using the proven technology of concentrating solar power (see Section 5), it is possible to capture some of this energy in the form of synthetic fuels. It is, for example, entirely feasible to create hydrogen by the electrolysis of water, using solar electricity. Solar heat may, in principle, be used to split water molecules directly or to synthesise fuels such as alcohol or hydrocarbons.

7.4 Electricity as a source of power for trains and road vehicles

Given the great potential that exists for generating electricity from renewable sources (Section 4.3 and Appendix 5), there is great scope for the use of electricity in powering trains and road vehicles. To replace fossil fuels in overland transport with renewable electricity would require less than 50% more electricity than we currently use (see Appendix 8).

Trains have been powered by electricity for many years and the technology is mature, but electric road vehicles currently have a 'milk float' image in the UK. However, this is really out of date since there are now several attractive and practical designs for electric cars and other kinds of road vehicles. A very useful source of information in this connection is the website of Electric Vehicles UK.[46]

Every day, the great majority of road vehicles travel less than the 100 mile range that is well within the scope of EVs now. But it will always be true that any vehicle may need to cover a longer distance in any one day, or will be needed for some important journey when the battery is flat. Hence, there is a good case for hybrid vehicles that can draw power from an ordinary engine when required. PHEVs—like ordinary hybrids but with larger batteries—give ample scope for the use of green electricity.[47] There is scope for incorporating photovoltaic panels in the roofs of vehicles so that they can draw some of their power directly from the sun. And, as mentioned in Appendix 7, PHEVs open up interesting possibilities for load-balancing on the grid.

In general, there is a need for the well-designed electric vehicles that already exist to be available in the UK at affordable prices, and soon .

7.5 Aviation

Notwithstanding EasyJet's recent claims,[48] the scope for significant reductions in CO_2 emissions from planes is very limited.[49] There appears to be some substance in George Monbiot's view that, given the urgent need for global reductions in CO_2

[46] See http://www.evuk.co.uk/ .
[47] See REA2006 and "Google searches for low-emission answers", Carbon Free News, 2007-06-20, http://www.carbonfree.co.uk/cf/news/wk25-07-0001.htm .
[48] "EasyJet unveils low-carbon 'eco-plane'", The Daily Telegraph, 2007-06-17, http://www.telegraph.co.uk/news/main.jhtml?xml=/news/2007/06/15/necojet115.xml .
[49] See also "Green sky thinking: eight ways to a cleaner flying future", New Scientist, issue 2592, 2007-02-22.

emissions, there is little option but to ground the majority of the world's planes (GM2006).[50]

But, since CO_2 emissions are the target rather than flying *per se*, I believe that people should be free to use their carbon allowances as they wish, within the context of a properly-administered system of Personal Carbon Allowances (Section 2.1 and Appendix 1) geared to annual reductions in UK emissions of CO_2 as proposed in the Climate Change Bill (Section 2.3 and Appendix 2).

Unless some radical new technology emerges for powering planes without releasing CO_2, it is likely that carbon rationing will have the effect of reducing their use.[51]

There is certainly no case for expanding UK facilities for air travel, which appears to be the Government's current intention.[52]

7.6 Shipping

Wind has been the main source of power for shipping for thousands of years and it can be so again. The advantage that we have now is that there is great scope for the use of modern technologies, as in the proposed 'Orcelle' cargo ship.[53] There is also scope for radical new possibilities such as the SkySails system.[54]

8 Conclusion

Every country in the world must play its part in solving the problem of climate change. Since the UK has emitted relatively large amounts of CO_2 since the beginning of the industrial revolution and, since our carbon footprint is still well above average, we have a clear responsibility to make deep cuts in CO_2 emissions, and soon.

Although climate change is as big a threat as war, the Government's response has not, so far, been sufficient to meet the challenge. Although the Energy Review and the Energy White Paper are moving in the right direction, there is a need for a much greater sense of urgency and much more coherence in UK energy policies.

This report has identified a number of areas that need attention:

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[50] "There is … no technofix. The growth in aviation and the need to address climate change cannot be reconciled. Given that the likely possible efficiencies are small and tend to counteract each other or to be unacceptable for other reasons, a 90 per cent cut in emissions requires not only that growth stops, but that most of the planes which are flying today are grounded.", GM2006, p. 182.

[51] In 2003, annual CO_2 emissions per capita in the UK were 8.9 tonnes (Wikipedia "List of countries by carbon dioxide emissions per capita", 2007-06-28). An economy class return flight between London and New York with 80% occupancy produces 1.4 tonnes of CO2 per passenger (using the calculator on http://www.chooseclimate.org/flying/mf.html). So two such flights per year represents 2.8 / 8.9 = 31% of the average per capita emissions in the UK. Of course 8.9 tonnes per person per year is too high. If current worldwide CO_2 emissions are distributed equitably amongst everyone in the world, each person would be able to emit about 4 tonnes (according to the World Resources Institute, average per capita emissions were 3.97 tonnes in 2002) and if this is reduced by 90% as seems to be needed to stabilise CO_2 levels in the atmosphere, each person would be able to emit 0.4 tonnes. This does not cover many flights between London and New York!

[52] "Government 'committed' to airport expansion", politics.co.uk, 2006-12-14, http://www.politics.co.uk/news/domestic-policy/environment/climate-change/govt-committed-airport-expansion-$461043.htm .

[53] See, for example, http://www.rense.com/general63/sea.htm .

[54] See http://www.skysails.info/index.php?L=1 .

- A coherent system of carbon rationing, including Personal Carbon Allowances, is needed to provide the right framework of incentives. There may also be a case for other incentives such as feed-in tariffs.
- The Climate Change Bill needs to be strengthened. We should be aiming for cuts of at least 90% by 2050, there should be an annual budget for CO_2 emissions, aviation and shipping must be brought within the scope of the Bill, the carbon footprint of UK imports should count as part of our emission, carbon offsets should not be used as a means of meeting UK targets for reductions in CO_2 emissions, and an independent body should take overall responsibility for administering the UK programme of emissions reductions.
- The problem of CO_2 emissions from buildings will not be solved by raising standards for new buildings. We need a vigorous programme of "zero-carbon eco-renovation" to bring emissions from existing buildings down to zero or nearly so. Demonstrators are needed to show how this can be done with different types of building.
- Renewable sources of electricity, with conservation of electricity, should be developed much more vigorously, following the lead of countries like Germany. There are more than enough renewable sources of electricity to meet our current and future needs and there is absolutely no need for nuclear power, with all its many headaches. Non-nuclear low-carbon scenarios can provide greater security of supplies than we have now. Hidden subsidies for nuclear power should be removed. When hidden costs are included, nuclear power is one of the most expensive sources of electricity.
- Given the huge potential of the DESERTEC proposals, governments throughout Europe and EUMENA should take whatever steps are needed to make them a reality.
- Given the major advantages and modest cost of establishing a EUMENA-wide or Europe-wide HVDC Supergrid and a single market for electricity, governments throughout these regions should collaborate to make them a reality.
- Greater support is needed for public transport and for walking and cycling. There is some scope for using bio-fuels in transport but there is probably much greater potential in the use of renewable electricity as the main means of powering trains and road vehicles. Since there is little prospect of substantial reductions in CO_2 emissions from planes, there is absolutely no case for expanding facilities for air travel in the UK. Clever use of wind power and other renewable sources of energy, can largely eliminate CO_2 emissions from shipping.

Appendices

Appendix 1: Personal carbon allowances

The basic idea is that each person is allowed to emit CO_2 derived from fossil fuels up to a limit which is their personal allowance. Unused 'rations', 'permits' or 'allowances' can be bought and sold. Each person's allowance is gradually reduced from year to year, with plenty of advanced warning of each reduction so that there is plenty of time to plan and adapt. Other names for this or related ideas include 'Personal Carbon Allowances', 'Domestic Tradable Quotas', 'Tradable Energy Quotas', 'Tradable Carbon Permits' and 'Domestic Tradable Carbon Rations'.

Tradable carbon allowances allow relatively direct control over emissions of fossil carbon and this is very different from the thoroughly unsatisfactory idea of trying to control emissions indirectly by means of carbon offsets (see below). Unfortunately, the term 'carbon trading' is applied to both ideas and this is a source of confusion.

The concept of tradable personal carbon allowances was originally proposed by Aubrey Meyer (founder and director of the Global Commons Institute[55]) and Mayer Hillman of the Policy Studies Institute.[56] It has also been developed by David Fleming (of the Lean Economy Institute) and has been the subject of detailed research by Kevin Anderson and Richard Starkey of the Tyndall Centre for Climate Change Research[57] and by Tina Fawcett and Catherine Bottrill at the Environmental Change Institute, University of Oxford.[58]

In a system of PCAs, the number of allowances that would be issued each year would be determined directly from the overall cap on emissions for the year, which should itself be set in the light of the best available scientific advice. The system would be administered by an independent body, in much the same way that interest rates are determined by the Bank of England. Members of the 'carbon authority' would be appointed on the strength of their technical competence, not their affiliation to this or that stakeholder group.

PCAs have several advantages compared with the alternatives:

- From a political standpoint, PCAs have the attraction that they are likely to create at least as many winners as losers (if the right number of permits are

[55] http://www.gci.org.uk/ .
[56] http://www.psi.org.uk/ .
[57] http://www.tyndall.ac.uk/ .
[58] http://www.eci.ox.ac.uk/index.php .

issued). This is because many people with relatively small incomes are likely to have surplus carbon allowances that they can sell for cash. By contrast, carbon taxes, often promoted as the way to discourage the burning of fossil fuels, mean that we are all losers (apart from the Government who collects the taxes). It is true that carbon taxes in one area can be offset by a reduction in taxes in some other area but this is difficult to communicate and there is the inevitable suspicion that green taxes are simply a means of increasing the overall tax take. In general, PCAs are likely to be much less of a political hot potato than carbon taxes.

- A related point is that an independent body that makes decisions based on objective measures frees politicians from the temptation to do what is politically expedient instead of doing what is right. Without this kind of independence and objectivity, politicians are far too vulnerable to political pressures.
- Again, with the possible exception of taxes on air travel, carbon taxes are likely to hit poor people disproportionately hard. For example, a 20% increase in the cost of fuels for heating is likely to be a much bigger thump in the pocket for a poor person than it would be for a rich person. With PCAs, that kind of worry disappears. Each person's ration is guaranteed and the only people who have to pay more are those who want to use more carbon than is provided in their ration.
- By contrast with the objectivity of PCAs, levels of taxes, tax breaks, subsidies, feed-in tariffs etc depend on relatively subjective judgements about what should be discouraged or encouraged and what the levels of taxes or grants should be.
- Carbon rationing gives the Government much more direct control over levels of CO_2 emissions than any other system. This kind of direct control will be needed if the proposed Climate Change Bill (DEFRA2007) becomes law, with mandatory annual cuts in UK emissions of CO_2.
- PCAs are an essentially simple mechanism that will produce a whole raft of incentives to reduce CO_2 emissions, right through the economy. The main alternative is a relatively complex combination of carbon taxes, grants, tax breaks, feed-in tariffs, renewable obligation certificates, subsidies, quangos, exhortation and special schemes, a system that is likely to create many anomalies and contradictions.[59]
- The cost to the Government and taxpayers is only the cost of administering the scheme: no expensive grants or tax breaks are required.
- PCAs provide a means of controlling 'external' UK emissions of CO_2. The CO_2 associated with goods or services from abroad should really count as part of the UK's emissions, otherwise there will be a great incentive to move all

[59] As an example of the kind of anomaly that can arise, the current system of Renewable Obligation Certificates for electricity generation (DBERR2007, pages 147-156) means that it is not possible for anyone to buy electricity that is truly 100% renewable. This is because a company like Good Energy, that claims to sell 100% renewable electricity, sells its surplus ROCs (in excess of its legal obligation) to other companies that are falling short, thus freeing them from the need to invest in renewable electricity. This means that electricity that is bought from Good Energy does not lead to any net increase in the amount of renewable electricity that is generated.

manufacturing or services to countries with very lax controls over CO_2. There are at least two answers to this problem:

- One is to create some kind of "World Carbon Organisation" that would regulate carbon emissions in every country, in much the same way that the World Trade Organisation regulates trade in countries that subscribe to the organisation.
- Until there is such a body, and it may be a long time coming, PCAs provide a partial solution. All goods imported from abroad would be assessed, and PCAs would be attached to each product line in proportion to the amount of CO_2 that is released in its production. This would raise the price of 'dirty' products and provide a clear incentive to the producer countries to clean up their act. It would also help to create more of a level playing field for UK-based manufacturers. Carbon taxes could be used in a similar way but, as described above, these provide a much less direct means of controlling CO_2 emissions than PCAs.

- If Contraction and Convergence (AM2000) is accepted as the model for global reductions in CO_2 emissions—any many now believe that this is the only satisfactory way of bringing down emissions in an equitable way—then PCAs are the obvious corollary.

Controlling carbon at source?

In Kyoto2.org,[60] a set of proposals for a successor to the Kyoto Protocol, there is the interesting suggestion that fossil carbon should be controlled at the point where it is dug or pumped out of the ground. Since there are far fewer coal mines and oil and gas wells in the world than there are people, it does look as if it would be much easier to control fossil carbon at its sources than at the point where people use it.

One difficulty with this idea is that, by itself, it would not be sensitive to the differing needs of different people or groups of people. Any system that controlled the amount of carbon that is taken out of the ground would drive up the price of fossil fuels. With higher prices, it is likely that rich people or rich countries would get what they need but poor countries and poor people would get even less than they do now.

There may be a case for controls of some kind over the extraction of carbon but, in accordance with the principle of Contraction and Convergence, it probably needs to be coupled with a system of rationing that protects the interests of poorer countries and poorer people.

PCAs, other carbon trading schemes and 'carbon offsets'

Although there may be a place for carbon trading schemes at the level of largish businesses (like the EU Emissions Trading Scheme), there are significant benefits in bringing carbon trading down to the level of individual people. The money economy is driven by billions of buy/sell decisions by individual people and it seems likely that the carbon economy would operate most efficiently in the same kind of way.

Issuing millions of allowances to individuals may seem complex but it should be no more difficult to administer than credit cards, debit cards or the loyalty schemes operated by

[60] http://www.kyoto2.org/ .

most supermarkets. The system of rationing that operated during and after World War II was administered successfully using only the lo-tec methods that were available then. If rationing could be done then, it can certainly be done now.

Carbon trading should not be confused with 'carbon offsets', the practice of paying money into schemes that claim to save CO_2 emissions that may be set against emissions from one's own activities. *For a variety of reasons, carbon offsetting is a thoroughly unsatisfactory idea*.[61]

Appendix 2: The Climate Change Bill

The main concerns about the draft Climate Change Bill (DEFRA2007) are as follows:

- The target of 60% cuts in carbon dioxide emissions by 2050 is not ambitious enough. Scientists now believe that deeper cuts are needed, and sooner. For example, researchers at the Tyndall Centre, Manchester, write that, if relevant parts of international aviation and shipping are brought within the scope of UK emissions, the UK should "reduce its carbon dioxide emissions by some 90% by 2050, and around 70% by 2030." (TC2006b, p. 9). In general, annual cuts in CO_2 emissions should be in accordance with the best available scientific advice.[62]
- *There should be an annual budget for CO_2*, not a five-year budget as suggested by the Government. It is true, as the Government says, that a cold winter might blow things off course. But the same kind of thing can be said about money—and in that sphere, annual budgets are the rule. An annual budget highlights any problem before it gets too bad and provides an opportunity to take corrective action. Since governments normally hold power for about four years, a five-year budget is an invitation to each government to blame the previous administration for any problems.
- Aviation and shipping *must* be included within the scope of the Bill.
- The carbon footprint of all goods and services imported from abroad should be assessed and that carbon footprint should count as part of the UK's emissions.
- The UK should not be allowed to meet its targets by buying 'carbon offsets' from abroad. There is far too much scope for schemes that are either futile (yielding no net cuts in CO_2 emissions) or simply fraudulent.[63]
- The system should be administered by an independent body (like the Bank of England's Monetary Policy Committee) composed of people appointed for their technical competence, not representatives of 'stakeholder' groups.

Appendix 3: The problems with nuclear power

The problems associated with nuclear power are numerous and many of them are serious:

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[61] For some discussion, see http://www.mng.org.uk/gh/mechanisms/carbon_offsets.htm .
[62] As noted in the Executive Summary, it is welcome news that Gordon Brown has indicated that higher targets are needed for CO_2 reductions in the Climate Change Bill.
[63] "The inconvenient truth about the carbon offset industry", The Guardian, 2007-06-16, http://www.guardian.co.uk/uk_news/story/0,,2104380,00.html . See also http://www.mng.org.uk/gh/mechanisms/carbon_offsets.htm .

- **Safety**. Right from the beginning of the nuclear power industry, we have been assured that the technology is safe. But: ■ There was a disaster at Windscale in 1957 (that would have been much worse if the wind had been blowing inland instead of out to sea);[64] ■ There was a partial meltdown at Three Mile Island in 1979; ■ The Chernobyl disaster in 1986 released large amounts of radioactivity over a very wide area; ■ There has been extensive radioactive contamination from the Dounreay nuclear reactor;[65] ■ In late July 2006 there was an accident at Sweden's Forsmark nuclear power station which was described as a near-meltdown by Lars-Olov Hoglund, a Swedish nuclear expert;[66,67] ■ According to the Whitehaven News (2007-01-04): "British Nuclear Group Sellafield was fined half a million pounds last year after admitting a radioactive leak, the size of a lorry load of thallium, and 160 kgs of plutonium." And so on …! *Assurances that such things will not happen in the future do not inspire confidence.*

- **Nuclear reactors, nuclear reprocessing plants and the trains that carry nuclear materials around the country are easy targets for terrorists**. This was demonstrated in July 2006 when a Daily Mirror reporter managed very easily to plant a 'bomb' on a train carrying nuclear waste.[68] Nuclear materials being transported around the world can easily be attacked or hijacked by terrorists.

- **When all the overt and hidden subsidies are taken into account, nuclear power is much more expensive than any other source of power**.[69] *To be competitive with other sources of power, nuclear power requires permanent support from tax payers or permanent support by means of market mechanisms or hidden subsidies.* By contrast, most renewable forms of energy need temporary support until costs are reduced by economies of scales and refinement of technologies, and no further support after that.

  One of the biggest of several hidden subsidies for nuclear power is that it is only required to pay a small fraction of the cost of insuring fully against claims from a Chernobyl-style disaster, or worse: "... in the United States, the Price-Anderson Act limits the nuclear industry's liability in the event of a catastrophic accident to $9.1 billion, which is less than 2% of the $600 billion guaranteed by the Congress. In any case, $600 billion is considered to be a gross underestimate ...".[70] There are similar limitations on liabilities elsewhere in the world, including the UK.

  Helen Caldicott says: "In France, if Electricité de France had to insure for the full cost of a meltdown, the price of nuclear electricity would increase by about 300%. Hence, as opposed to conventional wisdom, the price of French nuclear electricity is artificially low." (HC2006, p. 32).

  Full insurance against nuclear disasters would completely demolish any economic case for nuclear power.

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[64] "Windscale fire", New Scientist, 2006-11-18, http://www.newscientist.com/channel/opinion/classic-articles/mg19225780.014-windscale-fire.html .
[65] "How Dounreay's nuclear dream turned sour", The Scotsman, 2002-11-13, http://thescotsman.scotsman.com/index.cfm?id=1262682002 .
[66] See "How close did Sweden come to nuclear disaster?", Spiegel Online, 2006-08-07, http://www.spiegel.de/international/spiegel/0,1518,430458,00.html .
[67] "Nuclear shutdowns leave Swedes debating", International Herald Tribune, 2006-08-04, http://www.iht.com/articles/2006/08/04/news/sweden.php .
[68] See http://www.mng.org.uk/gh/renewable_energy/daily_mirror_nukes1.htm .
[69] NEF2005, HC2006.
[70] HC2006, p. 32.

- **Significant amounts of CO_2 are released by the nuclear industry**: in the construction of nuclear power stations and in the mining uranium ore, transporting and processing uranium ore to make nuclear fuel, transporting the fuel, transporting nuclear waste, processing it, and disposing of it. It is a long way from being a zero-emissions source of electricity, as claimed by the industry. Helen Caldicott[71] quotes research showing that "The use of nuclear power causes, at the end of the road and under the most favourable conditions, approximately one-third as much carbon dioxide (CO_2) emission as gas-fired electricity production." The use of poorer ores as a source of fuel for nuclear reactors "would produce more CO_2 emissions than burning fossil fuels directly." In other words, "nuclear reactors are best understood as complicated, expensive, and inefficient gas burners."
- **Nuclear power may consume more energy than it produces**. "Even utilizing the richest ores available, a nuclear power plant must operate at ten full-load operating years before it has paid off its energy debts. And ... there is only a finite supply of supply of uranium ore containing reasonable concentrations of uranium 235. When this concentration falls below 0.01%, the costs of energy production from nuclear power can no longer cover the costs of extraction of uranium from the earth, at which time the nuclear fuel cycle will produce no net energy; below a certain uranium content, nuclear power produces less energy than is needed to build, fuel, and operate the reactor and to repair the environmental damage."[72]
- **No solution has yet been found to the problem of disposing of dangerous nuclear waste**, much of which will remain dangerous for more than 10,000 years. *No human institution has ever survived that long.*
- Contrary to what many people imagine and often suggest as an advantage of nuclear power, it is not available 24/7 throughout the year. **Just like wind power, and all other sources of electricity, nuclear power is intermittent**. Nuclear power stations stop producing electricity during routine maintenance and unscheduled breakdowns, and the 'load factor' (the amount of electricity that is actually produced compared with the theoretical maximum) is normally well short of 100%.
- In its 'normal' operation, **the nuclear industry releases radioactivity into the environment** that causes damage to health.[73]
- The wide distribution in the world of plutonium and enriched uranium increases the chances that terrorists will be able to get hold of enough to make either **a 'dirty' conventional bomb or even an atom bomb**.
- The technology for nuclear power has much in common with the technology needed for the production of nuclear weapons. **The "Janus-like character of nuclear energy" (Kofi Annan) adds to the problem of reducing the number of nuclear weapons in the world or preventing their proliferation**. If we are trying to persuade countries like Iran to give up nuclear power, we are in a very weak negotiating position if we have nuclear power (and nuclear weapons) ourselves.
- **Security of supply**: all uranium is imported and supplies may be interrupted.[74]

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[71] HC2006, p. 6.
[72] HC2006, p. 16.
[73] These dangerous releases are well described in Helen Caldicott's book, detailed in footnote 1.

- **In recent heat waves, nuclear power plants have been shut down** owing to shortages of cooling water and unacceptable damage that would be caused by the discharge of hot water into the environment.[75,76] This kind of problem is likely to become worse as global temperatures rise.
- **Risk of flooding**. "Nuclear power stations on the British coast will experience storm surges up to 1.7 metres (5½ft) higher by 2080 because of global warming, a study suggests. The research, commissioned by British Energy, the nuclear plant operator, suggests that new coastal defence strategies may be needed to protect sites from a combination of more extreme weather and higher sea levels. All of Britain's 15 nuclear plants are near the coast, and the prospect of rising sea levels has raised questions about whether the sites will be suitable if a new generation of reactors is built."[77]
- **Nuclear power is an inflexible source of electricity** that is only suitable for 'base load'. It cannot respond quickly to peaks in demand for electricity.
- **Nuclear power only provides electricity**. It does not address the problem of reducing CO_2 emissions from space heating and road transport (except under the unlikely scenario that nuclear electricity would be used for a significant amount of space heating and charging of electric vehicles).
- Few science and engineering students are coming through to replace reactor workers who are now retiring. As a result **there will soon not be enough people to build and operate new reactors**. Without people who have the necessary knowledge and experience, it would be very unwise to try to build new nuclear power plants.
- It has been calculated that, if enough nuclear fission reactors were built to meet most of the world's demand for electricity, **exploitable sources of uranium would be exhausted in about fifteen to twenty years** (PM2005). If the more risky fast breeder reactors could be made to work reliably (not an easy job), this might yield fifty or sixty years of electricity. In a similar way, thorium could in principle be converted into nuclear fuel but this has not yet been shown to be practical and supplies of thorium are in any case limited.
- As exploitable sources of uranium become exhausted, **prices will rise**. *This is already happening*. And as higher-grade ores are exhausted, **more energy will be consumed** and **more CO_2 will be released** in processing the lower-grade ores that remain.
- The nuclear industry is notorious for **long lead times and overruns in times and costs**. Building a new nuclear plant is likely to be a long and costly process. The result may be a white elephant that is not able to compete with simpler and nimbler renewable technologies.

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[74] Nuclear power is not a 'home grown' source of energy as has been suggested by Malcolm Wicks, Minister of State for Energy in the UK Government: all the uranium needed for nuclear power is imported.
[75] "Climate change puts nuclear energy into hot water", International Herald Tribune, 2007-05-20, http://www.iht.com/articles/2007/05/20/africa/nuke.php .
[76] "Our nuclear summer", The Huffington Post, 2006-08-12, http://www.huffingtonpost.com/joel-makower/our-nuclear-summer_b_27112.html .
[77] Mark Henderson, The Times, 2007-01-24.

- **Opportunity cost**: As Friends of the Earth and others have been pointing out, money spent in propping up the nuclear industry is money that would be much more profitably spent on expanding renewable sources of energy and conservation.

Appendix 4: Zero-carbon eco-renovation

Contrary to the rather pessimistic conclusions of the "40% House" report (ECI2005), I believe that it should be possible to upgrade the great majority of buildings in the UK to a level comparable with a German "Passivhaus"[78] so that little or no heating is required. If the much-reduced needs for heating are supplied via such things as solar water heaters and ground-source heat pumps powered by green electricity, then it should be possible to achieve zero emissions of CO_2 or nearly so.

I believe that this kind of zero-carbon eco-renovation can be achieved by using existing techniques.[79] Of these, the most important are likely to be:

- Eliminating air leaks.
- Ventilation by means of heat exchangers, keeping air fresh but conserving heat.
- Triple glazing with low emission glass.
- Insulation of roofs, walls and the ground floor at levels far in excess of the kind of cavity wall insulation that is currently used. For a variety of reasons this is likely to mean external cladding. The thicknesses of insulation required are likely to be large, perhaps even as much as 1 metre!

Some attempts have been made to upgrade existing buildings along these lines[80] but it is likely that significantly more can be achieved. There is a clear need for a series of *Zero-Carbon Eco-Renovation Demonstrators*, showing what can be achieved with different kinds of building: traditional bungalow, 1960s tower block, terrace house, suburban semi, etc.

The T-Zero project[81] seems to be moving in this direction. The "BRE Victorian house of the future"[82] is the kind of demonstrator project I have in mind.

Since external cladding is likely to change the appearance of buildings (not necessarily for the worse[83]), changes in planning law will probably be needed to permit this kind of upgrading, with the possible exception of buildings with great historical or aesthetic significance.

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[78] See, for example, http://www.passivhaus.org.uk/ and http://www.passiv.de/ .
[79] See, for example, BRE2005.
[80] See, for example, the Nottingham Ecohome (http://www.msarch.co.uk/ecohome/) and the Yellow House (http://www.theyellowhouse.org.uk/).
[81] "Towards zero emissions refurbishment options in UK housing", funded by the DBERR, http://www.bre.co.uk/page.jsp?id=825 .
[82] http://www.bre.co.uk/newsdetails.jsp?id=397 .
[83] The appearance of many buildings, such as the many ugly public buildings that were put up in the 1960s, could be greatly improved by the application external insulation that has been designed with the intention of improving the appearance of the building as well as insulating it.

Appendix 5: Renewable sources of electricity and conservation of electricity

Sources of clean electricity for the UK, and methods of saving electricity, are briefly reviewed here, with an overall assessment of their potential:

- **Wind power** is one of the fastest-growing sources of energy worldwide. The British Wind Energy Association[84] says that "Our offshore wind resource alone has been estimated as enough to power the UK three times over." The proposed *European Supergrid* would smooth out much of the variability of wind power (Appendix 6).
- **Wave power**. The *Pelamis* wave energy converter[85] and other promising wave energy devices are already in commercial production. It is estimated that wave power could meet about 25% of UK demand.[86]
- **Tidal lagoons**[87] generate electricity at predictable times as the tide rises and as it falls, and they can double as pumped storage devices, helping to match supply and demand (Section 4.4). It is estimated that about 8% of UK electricity demand could be met from this source.[88] *A report from Friends of the Earth*[89] *concludes that tidal lagoons would have several advantages compared with the proposed Severn barrage.*[90]
- **Photovoltaic** 'solar panels' on roofs and walls could generate *at least* 20% of UK requirements. It has been estimated that as much as 266 TWh/y (about 66% of UK electricity demand) could be met from this source (TC2002, p 22).
- **Combined heat and power**. I very much endorse the view expressed by Greenpeace (GP2006) and others that waste heat from power generation should not be vented to the atmosphere but should be used for space heating and similar applications in systems for combined heat and power. *There should be a legal requirement that any new thermal power station makes full use of waste heat in that kind of way*.[91]
- **Conservation of electricity**. We are currently wasting large amounts of electricity. At least 2% of the UK's current demands could be met by replacing ordinary light bulbs with energy-saving versions, another 2% by eliminating 'stand-by' on TVs and similar appliances, and an additional 6% by the use of more efficient motors in industry. Further large savings may be made by introducing more efficient lighting

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[84] British Wind Energy Association, http://www.bwea.com/ .
[85] Ocean Power Delivery, http://www.oceanpd.com/ .
[86] http://www.oceanpd.com/Resource/default.html .
[87] Tidal Electric (http://www.tidalelectric.com/).
[88] Personal communication from Peter Ullman, Chairman and CEO of Tidal Electric.
[89] Described in a press release that may be seen here: http://www.tidalelectric.com/News%20FOE.htm .
[90] Several large lagoons enclosing the optimum shallow areas of the Severn Estuary, equivalent to a square of 11 miles by 11 miles, would: ■ Provide 6% of UK electricity demand (2.75 GW average); ■ Generate 30% more electricity annually from the Estuary at less than half the kWh output cost of the Barrage; ■ Impound an area 40% smaller than the Barrage and would not impede shipping to Bristol, Newport and other Severn ports; ■ Be sited about a mile or so offshore so avoiding the ecologically sensitive inter-tidal areas of the Estuary.
[91] For an example of a recent planning application that breaks this rule, see http://www.greenpeace.org.uk/blog/climate/say-no-to-new-coal-20070531 .

in the commercial sector and in city streets. At least 10% of UK electricity demand may be met by simple conservation measures (for details see FOE2006).

- **Concentrating solar power**, discussed in Section 5. In principle, this could meet all of Europe's demand for electricity but, as described in Section 5, it would be more sensible for it to be part of a balanced portfolio of renewable sources of power.
- Other potential sources of low-carbon electricity include geothermal power from Iceland,[92] carbon capture and storage (CCS), tidal streams, bio-mass and bio-fuels,[93] and small-scale wind turbines.

Potential

With few exceptions, the clean energy technologies that have been mentioned are ready to go now or will be soon. With the right framework of regulation and incentives, they can be brought on stream on relatively short timescales. I believe that, taken together, they can meet all current and anticipated future demands for electricity in the UK. Relevant figures are summarised in the following table:

[92] See "Iceland's hot rocks may be power source for UK", Sunday Times, 2007-05-13, http://www.timesonline.co.uk/tol/news/uk/article1782183.ece .

[93] I believe that is quite acceptable to make biofuels from materials that would otherwise go to waste (eg waste cooking oil, straw, waste from forestry or saw mills etc) and there is some scope for growing new biofuels, especially if they use the whole plant. But I agree with the many commentators who are pointing out that a rush to bio-fuels may raise the price of food, with the possible risk of malnutrition or even starvation, and bio-fuels may lead to the destruction of rainforest or other valuable natural ecosystems.

Electricity generation and conservation		% UK demand
Concentrating solar power		(at least) 15
Wind		(at least) 20
Marine		
Waves	25	
Tidal streams[94]	3	
Tidal lagoons	8	
Total (marine)		36
Microgeneration		
Photovoltaics	20	
Micro-wind[95]	6	
CHP and fuel cells[96]	16	
Total (microgeneration)		42
Electricity conservation		
Low-energy bulbs	2	
Eliminate 'stand by'	2	
More efficient motors	6	
Total (conservation)		(at least) 10
Other sources		(at least) 5
Total (% UK demand)		128

Appendix 6: Large-scale HVDC transmission grids

Here are some of the benefits of transmission grids, especially large-scale grids described below:

- Without a grid, electricity supply systems waste energy and this is particularly true with renewable forms of energy. If for example, the wind is blowing strongly in Scotland, producing more electricity than the local people can use, that surplus energy is simply wasted unless it can be moved to places where it is needed. Systems for bulk storage of electricity would make a difference but they would not remove the need to move electricity from areas of surplus to areas of need.
- Without a transmission grid, it would not be possible to take advantage of the large amounts of energy that may be obtained from large-scale but remote sources of renewable electricity such as wave farms, offshore wind farms, tidal lagoons, and tidal stream generators—and concentrating solar power.

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[94] CT2005a and CT2005b. The estimates in these two documents may be much too low. In "The rise of British sea power" (The Independent, 2008-03-23, http://www.independent.co.uk/environment/green-living/the-rise-of-british-sea-power-799630.html), Professor Stephen Salter of Edinburgh University is quoted as saying that the Pentland Firth alone could generate up to a quarter of Britain's electricity—more than is now being provided by all the country's nuclear power stations.
[95] EST2005.
[96] FOE2006.

- Another advantage of transmission grids is that, if they cover a large area like Europe, they reduce the variability of energy sources such as wind. The wind may stop blowing in any one spot but it is very rare for it to stop blowing everywhere across a wide area like Europe.
- A transmission grid helps to reduce the amount of 'plant margin'—the difference between actual generating capacity in any area and the theoretical minimum generating capacity—that is required. This is because spare generating capacity that is needed to meet contingencies can be shared across a relatively wide area, thus reducing the amount that is allocated to any one area.
- A related point is that *large-scale transmission grids help to ensure the security of electricity supplies in any one area*. This because any local shortage of electricity or local peak in demand can almost always be met from one or more other areas where there is spare capacity.
- A large-scale transmission grid throughout an area like Europe makes it easier to create a single market for electricity in that area (as we have in the UK) and that promotes competition between different suppliers and sources of electricity, seeking out the best.
- Transmission grids that cross time zones may increase the value of electricity by moving it, at any one time, from areas where it is cheap to areas where it will fetch a good price. More generally, large-scale grids allow customers to obtain electricity from wherever it is cheapest at any one time, and that may vary throughout each day.
- An HVDC Supergrid (see below) can help to stabilize frequencies and voltages in the HVAC grids to which it connects.
- From a UK perspective, with its huge potential for wind power, wave power, and power from tidal lagoons and tidal streams, stronger grid connections to the continent will facilitate exports of renewable electricity.

HVAC and HVDC

The high-tension power lines that most people are familiar with use alternating current (AC) for reasons that were worked out by Nikola Tesla—a fascinating story in its own right. High voltages are needed to ensure that electricity can be transmitted over long distances without losing too much of the energy in the form of heat. AC has the advantage that voltages can be raised or lowered easily using transformers. Nikola Tesla invented an electric motor that would run on AC electricity to save having to convert it to direct current (DC).

But over very long distances, AC transmission lines become increasingly inefficient (because of the effects of capacitance and impedance in the system). So, although voltage conversions are not so easy with DC electricity, long distance transmission lines use DC electricity.[97] With modern HVDC transmission lines, transmission losses are very low (about 3% for each 1000 km). And they are also cheaper to build than HVAC lines because only two lines are needed instead of three.

[97] For similar reasons, submarine cables normally use HVDC.

HVAC and HVDC transmission lines are often carried over land via pylons because this saves the cost of insulating the cables. But, for extra cost, they can be insulated and laid under the ground or under water.

Large-scale HVDC transmission grids

Given the advantages of transmission grids detailed above, and given the advantages of HVDC transmission lines for long-distance transport of electricity, there are several proposals to build large-scale HVDC transmission grids:

- A Europe-wide Supergrid has been proposed by the wind energy company Airtricity as a means of reducing the effects of intermittency in wind power across Europe and to facilitate the trading of electricity. In this proposal, it is envisaged that all the cables would be laid under the sea.[98]
- The TREC group propose an HVDC grid spanning the whole of Europe, the Middle East and North Africa (EUMENA) to take advantage of the enormous quantities of energy falling as sunlight on hot deserts, and wind energy in those regions too (see TCSP2006).
- A report in Engineer Live (EL2006) describes a proposal for a world-wide grid of HVDC transmission lines.

These grids would not replace existing HVAC grids: they would be designed to integrate with them and complement them.

In line with the European Supergrid concept, a recent report from the University of Oxford (OTF2007) calls for "completion of the physical European grid for ... electricity".

Appendix 7: Matching electricity supplies with demand

As mentioned in Section 4.4, the problem of matching variable electricity supplies with variable demand can be met by providing some combination of 1) spare generating capacity; 2) 'peaking power': sources of electricity that can respond quickly to peaks in demand; 3) methods for storing power; 4) methods for managing demand; 5) large-scale transmission grids (discussed in Appendix 6).

Spare generating capacity

The provision of spare generating capacity does not require much comment except to say that, as new renewable sources of electricity come on stream, it would make sense to put some of the older and dirtier generating plants into semi-retirement as backup sources of power. Also, the provision of large-scale transmission grids can help to reduce the amount of spare generating capacity that is required (Appendix 6).

[98] See http://www.airtricity.com/scotland/wind_farms/supergrid/offshore_supergrid_layout/ and the European Offshore Supergrid Proposal (AT2006).

Base load, intermediate load and peaking power

The ability to respond quickly to peaks in demand—peaking power—is one of the most useful characteristics of a source of electricity. But there is also a need for 'base load' power and 'intermediate load' power.

Coal-fired power stations cannot be switched on and off quickly so for many years the UK has relied on the wasteful and polluting practice of keeping some coal-fired power stations on 'spinning reserve' so that their output can be ramped-up quickly.

The "dash for gas" in the UK has reduced this problem because gas-fired power stations are more flexible.

An interesting feature of concentrating solar power (Section 5) is that it is possible to store solar heat in melted salts, and gas may be used as a stop-gap source of heat when there is not enough sun.[99] With these two features, CSP plants can supply any combination of base-load power, intermediate-load or peaking power, making them one of the most useful sources of electricity for matching supplies to demand.

There is already 2 GW of small diesel generating capacity used primarily for emergency standby in hospitals, water works and the like, which is used under contract by the National Grid, to assist in stabilising grid frequency during power swings. This 2 GW can be increased very cheaply to 20 GW by bringing in the large numbers of diesel backup plants that are not currently in the scheme.

If or when PHEVs[100] become widely used (Section 7.4), then there is the interesting possibility of using them as reserve sources of electricity.[101] If there is a shortfall in supply, signalled by a small drop in the frequency of AC current, then vehicles that are currently plugged in may start their non-electric motors and feed electricity into the grid. Naturally, this should only happen when a vehicle is parked in a position where exhaust fumes can easily disperse.

Storing power

The UK has some pumped-storage facilities[102] but there seems to be little scope for expanding that provision. Bulk storage of electricity is possible with flow batteries[103] but these are still quite expensive. As mentioned in the previous section, it is possible to store solar heat in CSP plants and this could become increasingly useful as CSP imports come on stream.

An interesting aspect of tidal lagoons (described briefly in Appendix 5) is that they may double as pumped storage devices (see DJCM2007).

Managing demand

An interesting option for matching supplies to demand is the concept of 'dynamic demand'.[104] The general idea is to take advantage of the fact that some appliances, such as fridges, cold stores or PHEVs (see REA2006) do not normally need to draw electricity at

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[99] See http://www.trec-uk.org.uk/csp_sections/csp_no_sun.htm .
[100] Plug-in Hybrid Electric Vehicles.
[101] See REA2006 and "Google and utility to test hybrids that sell back power", New York Times, 2007-06-19, http://www.nytimes.com/2007/06/19/technology/19electric.html?_r=1&ref=busine .
[102] Such as the Dinorwig pumped-storage system near Llanberis in North Wales.
[103] See, for example, NS2007.
[104] See http://www.dynamicdemand.co.uk/ .

any particular moment but may delay their demands until there are adequate supplies. As mentioned earlier, a small drop in frequency indicates a shortfall in supplies and appliances that are fitted with a suitable detector may be designed to draw power as far as possible when the frequency is normal.

Appendix 8: Electricity as source of power for transport by road and rail

If, as I believe, there is great potential for the generation of renewable electricity (see Appendix 5), it may be possible to use it as a significant source of power for transport by road and rail. This could make a very useful contribution to bringing down UK emissions of CO_2.

If that kind of revolution in road and rail transport were taken to its logical extreme, an obvious question is "How much extra electricity would be needed?" The calculations shown here are based on a snapshot of energy uses in the recent past without any attempt to predict changes in the future.

In 2005, the quantities of energy consumed in transport by road and rail were as shown in the following table:[105]

Type of transport	1000s TOE[106]	TWh
Road		
Cars	26834	312
Freight	15501	180
Rail		
Electric	740	9
Fossil fuels	869	10
Total	43944	511

To simplify things in the following calculations, I shall focus on the 312 + 180 = 492 TWh of energy used for road transport and ignore the relatively small amounts of energy used for rail.

If the whole of road transport was electrified, then at first sight, the UK would need an additional 492 TWh of electricity, over and above the 407 TWh that was used in 2005.[107] But batteries and electric motors are relatively efficient:

- "The coulometric charging efficiency of nickel metal hydride batteries is typically 66%, meaning that you must put 150 amp hours into the battery for every 100 amp hours you get out."[108]
- "Electric motors often achieve 90% conversion efficiency over the full range of speeds and power output and can be precisely controlled."[109]

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[105] From "Table 2.1. Transport energy consumption by type of transport and fuel, 1970 to 2005", Department of Trade and Industry statistics, http://www.dti.gov.uk/energy/statistics/publications/ecuk/transport/page18043.html .
[106] Tons of Oil Equivalent.
[107] The latter figure is from DBERR2006a, p 114.
[108] http://www.powerstream.com/NiMH.htm.
[109] Wikipedia, "Fuel efficiency in transportation", 2007-06-24.

If we take those two figures as representative, the overall efficiency of an electric vehicle would be about 90% of 66% or 59% overall, ignoring losses of energy elsewhere in the vehicle. By contrast, the efficiency of an internal combustion engine is normally about 20%.[110]

With our current road transport system, based almost exclusively on the internal combustion engine, the useful energy obtained from an input of 492 TWh will be about $492 \times 0.2 = 98.4$ TWh. To obtain this amount of useful energy from electric vehicles with an efficiency of 59% would require $98.4 \times 100/59 = 166.8$ TWh of electricity. This is less than 50% of the 407 TWh that we currently use.

[110] Wikipedia, "Internal combustion engine", 2007-06-24.

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