

Environmental Audit Committee Inquiry
Keeping the Lights On:
Nuclear, Renewables and Climate Change

Memorandum by
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Summary

The UK has an energy problem... we use too much. As we enter an era of declining energy resources we must recognise and address this fact in the shortest possible time-scale.

Electricity is a means of carrying energy between two points. There is nothing intrinsically *special* about electricity as a carrier of energy, as compared to other conventional fuels. Therefore, in evaluating the future for electricity generation, we need to open up the debate to a far wider evaluation of how we use energy today. In fact, electricity consumption in the UK is only 18% of the final quantity of energy supplied to the economy; the amount of energy consumed as natural gas in the UK is far larger than the amount of energy consumed as electrical power. Consequently, the Committee must address the wider trends in energy use in order to ensure that the other 82% of the energy we consumed in the UK is not omitted from their deliberations.

Another issue not addressed in the questions posed by the Committee are the effects of global trends in future energy supply, in particular the global peak in both oil and natural gas production. Very simply, peak oil/peak gas is the point at which the level of production that can be sustained from the world's oil and gas fields can no longer meet the demands placed upon them. Our own North Sea oil production peaked in 2000, and most current projections place the global peak in oil production in 2007. Our North Sea gas production peaked recently, and the Parliamentary Office of Science and Technology cites a peak in global natural gas production occurring between 2020 and 2030.

The Environmental Audit Committee's inquiry puts emphasis on the 'new build' of nuclear power plants. However, there is a key question omitted from the list of matters provided by the Committee – *uranium resources*. Most of the nuclear reactors around the globe use thermal reactor technology. The problem for the nuclear industry is that only 1% of the uranium resource can be utilised by thermal reactors – the rest is ultimately rejected.

The seemingly unlimited amounts of uranium alluded to by the nuclear industry are a fallacy because the figures do not take account of the energy required to extract the uranium. In reality there is a cut-off point beyond which the extraction of uranium is futile because the processing requires more energy than the uranium will ultimately produce. Primary uranium currently supplies around half the world's 64,000 tonnes/year demand, with the other half coming from ex-military uranium stocks. If we take global reserves at 4 million tonnes, this gives a resource lifetime of 62.5 years. However, if the nuclear industry were to expand by five times, and assuming there is no significant increase in thermal efficiency in nuclear plants, then uranium demand would rise to 320,000 tonnes per year, and the lifetime of the resource reduces to 12.5 years. Consequently, it would be unwise to discuss building new nuclear capacity without a thorough investigation of uranium resources, and the effect of reactor technologies and uranium production on the longevity of the nuclear option.

Renewable energy sources are limited by the area of land required to intercept a sufficient 'flux' of energy to meet our energy demands. For example, producing biodiesel for just the cars registered on the UK's roads would require a land area slightly larger than the UK, and growing biomass to service our current electricity demand would require an area 2.5 times larger than the UK.

The first stage in the process of developing truly sustainable energy resources within the UK would be to decentralise the national grid. This would allow a greater proportion of our energy demand to be met from local sources, which in turn allows for a greater diversity of efficient generation and renewable energy sources to be developed.

To ensure our future energy security we should look within our own borders to meet our energy needs. Across all sources, 40% of our current energy demand could be met from renewable energy sources. Using current technologies cutting energy consumption by 60% to meet this target is achievable, but adapting to a low energy economy would require a wholly new economic paradigm. This may sound incredible, or unachievable, but it has happened before. During the 18th Century the UK experienced a comparable change in its social and economic organisation with the coming of the Industrial Revolution.

We face a very simple choice. We cut our energy consumption, or progressively higher energy prices over the next two to three decades will cause immense damage to our national well-being. Instead of focusing on building new generating capacity, conventional or nuclear, the Committee should investigate the development of 'negative capacity', or *nega-Watts*. This will be more expensive in the short-term. However, an imminent downturn in global energy supply, with a commensurate rise in prices for all types of energy, means that it would be wrong to evaluate the costs of a transition to a low energy society using current prices as a baseline. Instead, the Committee should price various strategies in terms of energy and economic impacts at specific points in the future.

Unless we adopt such a course of action soon, the economic damage wrought by a declining global economy, as global energy resources shrink, will make the process of transition far more unpleasant. In order to adapt to a contracting global energy supply over the next century our future well-being must be linked to our capacity to use *less* energy.

Introduction

1. I have produced this paper to outline a number of issues related to our future energy supply. Whilst I understand that the Committee's primary interest is in the UK's electricity generating system, I believe that any discussion of electricity generation must take place within the wider debate over resource use across society as a whole.
2. I set up Mobbs' Environmental Investigations in early 1992, and since then I have worked as an independent environmental consultant for community-based organisations across the UK. My approach is multi-disciplinary, mixing environmental science, engineering and law, in order to produce a holistic view of the problems I am asked to investigate. Over the past thirteen years I have taken part in numerous public inquiries, I have assisted individuals and organisations in remedying breaches of environmental regulations, and I have assessed many applications for development and pollution control authorisations.
3. More recently my work has involved in-depth research into specific areas. For the last three years I have been working, in association with networks of local community organisations, on the issue of *energy futures*. This work led to the publication of my recent book, *Energy Beyond Oil* [Mobbs, 2005]. My work on energy has also attracted interest from, and the publication of articles by, organisations such as Chatham House [RIIA, 2004], the Oxford Institute for Energy Studies [OIES, 2005] and the national media [Times, 2005].
4. The most important factor to bear in mind when evaluating the future of the UK's generating capacity is that electricity is a means of carrying energy between two points. There is nothing intrinsically *special* about electricity as a carrier of energy, as compared to other conventional fuels – other than the far greater level of flexibility and control it provides in comparison to other energy sources. Therefore in evaluating the future for electricity generation this paper does not assume that the prime decision should be on the future composition of our generating capacity. Instead, by looking at the thermodynamics of energy use within society as a whole, we need to open up the debate to a far wider evaluation of how we use energy today.
5. One of the key features of the Environmental Audit Committee's call for papers for its inquiry was the emphasis on the 'new build' of nuclear power plants for power generation. Quite naturally then, the questions posed by the Committee tend to focus on the practicality and acceptability of nuclear powered generation. However, there is a key question omitted from the list – *the issue of uranium resources*. I believe that it is unwise to discuss building new nuclear capacity without a thorough investigation of uranium resources, and the impact of reactor technologies and uranium production on the longevity of the nuclear option.

6. It is important that we phrase the debate on electricity supply in terms of its relevance to the UK's energy economy. In reality, electricity consumption in 2004 was only 18% of the energy supplied at the point of use [DUKES, 2005a]. In other words, the Committee must address the wider trends in energy use in order to ensure that the other 82% of the energy we use in the UK is not omitted from their deliberations.
7. Another issue that is not clearly addressed in the questions posed by the Committee are the effects of national and global trends in present and future energy use, and how these might affect the electricity supply industry. Clearly the key trends in the next two to three decades are the global peaks in both oil and natural gas production. The UK's production of both oil and natural gas has peaked in recent years, but the global peaks in oil and gas production create a far greater challenge to our economic and social well-being. The role of electricity, and the extent to which renewable sources of energy can make-up the shortfall in oil and gas, is a critical factor in how we address a global downturn in the availability of energy.
8. Finally, if we are looking at a downturn in global energy supply, with the obvious effect that prices for all types of energy will be higher, then it would be wrong for the Committee to look at the costs of different energy sources in terms of today's prices. In deciding what strategy to adopt in the future the Committee must review the various energy technologies available in terms of their relative costs in the future, not with reference to today's energy prices.

Electricity vs Energy – electricity as a subset of energy use

9. As noted in the introduction, electricity is not an *energy source*, it is a *carrier of energy*. We must therefore draw a distinction between the use of electricity in society and the overall demand for energy. Whilst electricity may be able to supplant the use of other fuels, it is produced, inefficiently, from a narrow range of other energy sources. Expanding the use of electricity in society has a serious effect on energy efficiency, the consumption of fuel, and consequently the emission of pollutants. But these impacts relate directly to the fuels used to generate power, not the the process of electricity generation itself.
10. By definition, within the government's current framing of the debate, any inquiry into the future of nuclear or renewable energy is an inquiry into electricity generation. However, concentrating on electricity production ignores perhaps the most valuable contribution of renewable energy in a temperate zone – *heat*. For each £1 invested, thermal solar systems provide 30 to 40 times more energy as heat than photovoltaic systems provide as electrical power. Likewise, the use of heat pumps to extract low-grade energy and to recover/recycle the energy discarded via waste air and water can reduce the demand

for energy by two-thirds or more. Therefore if the Committee ignores the heat generating renewable energy sources, when in reality a large part of the energy we consume is to produce heat (around 70% in the average household), it will significantly under-estimate the role that renewable energy sources might play in our future energy economy.

11. Electricity is not, perhaps contrary to the popular conception of our energy supply, the largest source of energy within the UK economy. I believe that it is important for the Committee to analyse the energy question in terms of our total use of energy, not just electricity. It's also important to understand that, in 2004, although nuclear power provided just under 20% of the UK's electricity, it provided less than 8% of the UK's entire energy supply [DUKES, 2005a]. Using the *million tonne of oil equivalent* (mtoe) as a common measure across all fuel sources, in 2004 the UK economy (or rather, the UK's *primary energy supply*) took in 234.9mtoe [DUKES, 2005c]. Of this total, *primary electricity* – the power produced by nuclear plants in the UK – made up only 18.3mtoe, or 7.8% of the UK's primary energy supply. Renewable sources accounted for just 0.82mtoe (0.3%) of the primary energy supply, and waste combustion/digestion, which the DTI also regard as “renewable”, 3.3mtoe (1.4%) [DUKES, 2005h].
12. A significant proportion of the energy consumed by the UK is supplied to power plants where it is 'transformed' into electrical power (see table 1). Currently just under one-third of the UK's primary energy supply is used to produce electrical power by the “major electricity generators”. However, electricity only makes up 29.2mtoe of the 161.1mtoe (or 18.1%) of the energy that is directly 'consumed' by the UK economy (the *final supply* or *final consumption* of energy) [DTI, 2005a]. This difference between the proportion of primary fuel consumed, and the balance of electricity within final supply, exists because 60% of the energy utilised by the major power generation companies is “wasted” – lost to the environment as a result of inefficient power generation.

Table 1. Energy Supply and the Energy Used for Power Generation, 2004

	<u>Oil</u>	<u>Coal</u>	<u>Gas</u>	<u>Nuclear</u>	<u>Other</u>	<u>Total</u>
Primary energy supply	76.5	39.3	96.1	18.2	4.8	234.9
Used for power generation	0.6	30.4	26.2	18.2	1.6	76.8
<i>proportion of primary supply</i>	<i>0.7%</i>	<i>77.3%</i>	<i>27.2%</i>	<i>100.0%</i>	<i>32.3%</i>	<i>32.7%</i>
Power produced (gross)	0.2	11.0	12.1	6.9	0.7	30.8
<i>efficiency of generation</i>	<i>28%</i>	<i>36%</i>	<i>46%</i>	<i>38%</i>	<i>46%</i>	<i>40%</i>
Energy “wasted”	0.4	19.4	14.1	11.3	0.8	46

All figures are in million tonnes of oil equivalent – mtoe
Sources: DUKES, 2005c; DUKES, 2005d; DUKES, 2005e

13. Despite appearances, we still live in the steam age. All of our conventional and nuclear power plants raise steam by using an energy source to produce heat. Then, using steam turbines (similar to the original system developed by Charles Parsons in 1884)

the energy of the steam is converted into torque, which drives generating sets to produce electrical power (the principles of which were established by Faraday in the 1830s). In 2004, the gross thermal efficiency of our power generation systems was 46% for combined-cycle gas turbines (CCGTs), 38% for nuclear stations, and 36% for coal-fired stations [DUKES, 2005b]. Spread over all generating sources the efficiency of generation was 40%. In other words, every 1kWh (kilo-Watt-hour) of power consumed in the UK entails the wastage of 1.5kWh of energy, mostly as heat dumped into the air or local rivers (note that in the South East and East Anglia, where drought is a serious problem, this also incurs a serious loss of water resources to the atmosphere). Consequently, whether the fuel source is coal, oil, gas, renewable biomass or nuclear, the thermal efficiency of steam-raising power generation plants has a far greater impact on the economics and emissions of power production than the fuel selected to produce the thermal load.

14. In 2004, domestic energy consumption only accounted for 30% of the UK's final energy consumption [DTI, 2005a]. The transport sector consumed 36% and the industrial and service sectors combined consume 34%. Energy consumption in the domestic sector is dominated by natural gas (70% of domestic energy comes from natural gas whilst only 20% comes from electricity [DUKES, 2005f]), whilst in the industrial and manufacturing sector electricity and natural gas are used in roughly equal amounts. Where electricity does dominate is in the commercial and retail sectors, where it makes up around two-thirds of the energy consumed.
15. The fact that electricity makes up only a minor part – 18.1% to be precise – of final consumption of energy in the UK means that if the Committee concentrates solely on the generation of electricity it will ignore the major part – 81.9% – of the energy problem. For example, the amount of natural gas consumed directly in the UK is far larger than the amount of energy consumed as electrical power. This issue is significant because of the demise of natural gas as a major source of energy in the near future (outlined below in relation to 'peak gas'). In this context, I believe it is valid to raise the question of whether it is worthwhile worrying about the future of less than 8% (the nuclear component) of the UK's energy supply when 84% (the oil and gas) will soon begin to run short, and hence become very expensive, in the next one or two decades.

Future Energy Supply – peak oil, peak gas, and the price of energy

16. Whilst not directly related to the questions posed by the Committee, I believe that it is important that the Committee consider two trends that have the potential to cause serious problems for the UK's energy economy in the near future: *Peak Oil* and *Peak Gas*.

17. Most global authorities on energy quote the future lifetime of energy reserves in terms of a *reserves/production ratio* (or *R/P ratio*) – dividing the available reserve by the current consumption in order to produce an availability in years. In fact, the geophysical restrictions on the production of energy minerals mean that such a linear relationship does not exist, and in reality production follows a bell-curve. This is because the production of energy minerals is dependent not just upon the available proven or probable reserve, but also the quality of the reserves and the speed at which the minerals may be extracted.
18. In the late 1940s a leading US geologist, Marion King Hubbert, looked at the production of oil from oil fields in the 'lower 48' states of the USA. He published various papers on his research, but the most important is considered to be his 1956 paper produced for the annual meeting of the American Petroleum Institute. In this paper he predicted that, based on trends in the discovery and growing consumption of oil in the USA, US oil production would peak in 1970 (see figure 1). Despite various criticisms of Hubbert over the intervening period, it was shown in the early 1970s that US oil production did indeed peak in that year, and the trend in the production of oil before and after the peak matched Hubbert's predictions.

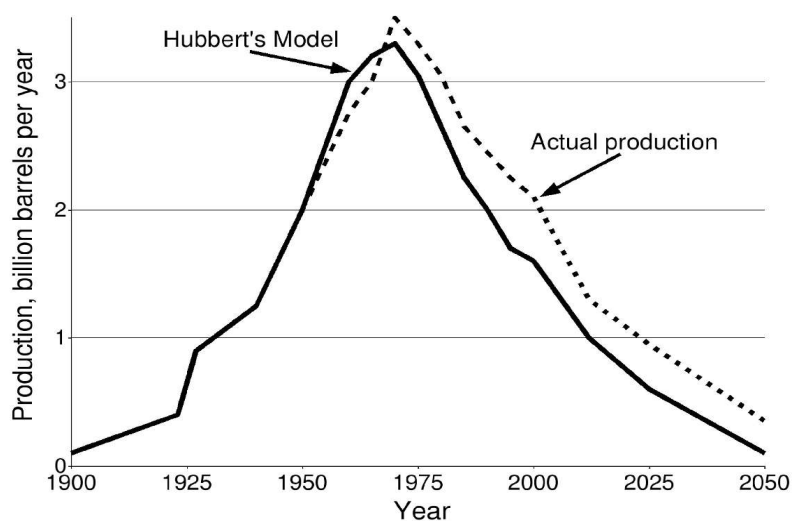


Figure 1. Hubbert's Peak or Hubbert's Plot

Source: Mobbs, 2005

19. Very simply, peak oil is the point at which the level of production that can be sustained from any oil field can no longer meet the demands placed upon it. Our own North Sea oil production peaked in 2000 (in fact, production fell by over 10% between 2003 and 2004), and other major oil fields around the globe are following predicted trends as they either progress towards or pass their peak of production. The controversial issue today is the use of Hubbert's method to predict a global peak in oil production.
20. Currently, most of the studies that use proven oil reserves as their basis predict a global

peak in 2007. In fact, recent data from the US Energy Information Administration tends to confirm this date as they predict [USEIA, 2005] that average global oil demand will equal average global oil supply in late 2006. This is in contrast to the position of the US Geological Survey (USGS – whose figures in turn form the basis of the predictions of the International Energy Agency) who predict that global oil production will peak around 2035. However, the USGS's 2035 figure was produced as part of a *probabilistic analysis* of future oil production, and it only has a 50/50 chance of being right. If we work at the 95% confidence level, the USGS data in fact suggests a peak nearer 2015.

21. There are many variables involved, such as the dynamic interaction between rising prices and consumer demand which, at the global scale, may turn the neat Gaussian peak predicted by Hubbert into a more drawn-out plateau or *bumpy peak*. In any case, the concerns recently expressed about the accuracy of Middle Eastern oil reserve data could mean that recent supply problems may be indicative of an impending peak. It's not just the inability of OPEC to produce more oil that is indicative of a peak, but also the fact that more of the oil produced by the Gulf states is now heavy (or sour) crude, not the light (or sweet) crude that the world relies upon for the production of fuel oil.
22. Natural gas production undergoes a similar trend to oil. The UK's natural gas production plateaued between 2001 and 2003, and production is now falling. This decline in production, coupled with strongly increasing demand for power generation, means that the UK is now importing ever greater volumes of gas each year. In fact, even with the development of liquefied natural gas (LNG) import terminals near London and in West Wales, concerns are already being expressed as to whether the UK can supply its demand for gas during a severe Winter [NGT, 2005]. According to the Parliamentary Office of Science and Technology, global natural gas production is likely to peak sometime between 2020 and 2030 [POST, 2004] with similar consequences to the peak in oil supply. However, Peak Gas represents a more significant point in time because from that date the globe's total energy supply will steadily contract until a new, primarily renewable-powered, equilibrium is reached (perhaps at the end of this century).
23. The peaking of global oil and gas production does not mean that we are going to imminently run out. Peaking occurs half way through the lifetime of the resource, and so an amount of oil/gas equal to that already extracted is likely to be available from that date on. What will be problematic for the UK is that the year-on-year fall in production capacity will drive prices for oil and gas ever higher, as countries compete on price to secure access to the remaining production. This has significant implications for the UK economy because we are so dependent upon petroleum products. However, if current trends continue (and we ignore the economic effect of rising prices), by the date of Peak Gas the UK could be dependent on gas-fired generating capacity for the majority of its electricity supply, and the majority of its space heating requirements.

Nuclear Power and Uranium Supply

24. Nuclear power may appear to be a solution to a downturn in gas supplies. However, nuclear plants also have a potential fuel supply problem in the future, depending upon how fast the nuclear states develop their generating capacity over the next few decades.
25. Globally, using BP's global dataset, nuclear power provides 6.1% of global energy consumption [BP, 2005]. Using this same dataset, the UK produces around 8.0% of its primary energy consumption from nuclear. However, to make any significant difference to a downturn in global oil and gas supply, or at a debatable level, to climate change (for example, by displacing the use of coal), the capacity of the nuclear sector would have to grow by at least five times. This has significant implications for the future of the globe's uranium reserve.
26. Most of the nuclear reactors around the globe use *thermal* reactor technology. Slow neutrons are used to fission atoms of one uranium isotope, uranium-235 (^{235}U), to produce heat. At the same time some neutrons are captured by another isotope of uranium, uranium-238 (^{238}U), and are converted (indirectly) to plutonium-239 (^{239}Pu). The fissioning of this 'bred' plutonium produces around one-third of the heat load created by the thermal reactor. In terms of the uranium resource, the problem for the nuclear industry is that ^{235}U only makes up around 0.7% of the world's uranium. Therefore, including the uranium converted to plutonium, only about 1% of the uranium resource can be utilised by thermal reactors – the rest (made up of ^{238}U) is ultimately rejected.
27. Rather like oil reserves, there is some debate over how much usable uranium there is available around the globe. The International Energy Agency assess uranium reserves in terms of the costs of production – they estimate there are around 4 million tonnes of uranium recoverable for less than \$130/kilo [IEA, 2001]. The European Commission have put the figure at 2 million tonnes [EC, 2001]. However, some figures in the nuclear industry quote the amount of recoverable uranium as being in excess of 4 billion tonnes [Price, 2002]: this figure is based on the theoretical amount of uranium on the Earth's surface irrespective of whether its recovery is feasible/economic or not. However, the seemingly unlimited amounts of uranium alluded to by the nuclear industry are a fallacy because the figures do not take account of the energy required to extract the uranium in a form suitable for the production of nuclear fuel. In reality there is a cut-off point beyond which the extraction of uranium is futile because the extraction and processing operations require more energy than the uranium will produce. This concept, called the *Energy Return On Energy Invested* (EROEI), is ultimately the limiting factor on how much energy we can produce from nuclear energy.
28. The EROEI for uranium is linked to the quality of the ore used to produce nuclear fuel. The lower the ore quality, the more rock must be processed, with a consequential

increase in energy consumption. Recent data from the World Nuclear Association [WNA, 2005a] puts the energy cost of running a reactor (including uranium production and operation/decommissioning of the plant – but not the final disposal of radioactive wastes) at a few percent of the plant's output. However, this analysis is based upon ore with a uranium content of 0.2% (2,000 parts per million, or ppm). As lower quality ores are utilised the proportion of the plant's output used in the production of the fuel will grow, and hence, progressively, the net energy production of the nuclear sector as a whole will fall. A 1975 study put the cut-off point, where the energy used to produce power exceeded the energy content of the uranium ore, at 0.002% (20ppm) [Chapman, 1975]. Such a value would exclude many of the more diffuse sources of uranium, and would reduce the amount of usable uranium to just a few million tonnes.

29. Currently the low price for uranium, in part created by the release of ex-military stocks of uranium onto the market, means that only the highest quality ores are mined. Primary uranium currently supplies around half the world's 64,000 tonnes/year demand, with the other half coming from ex-military uranium stocks. If we take global reserves at 4 million tonnes, this gives an R/P ratio of 62.5 years. However, if the nuclear industry were to expand by five times, and assuming there is no significant increase in thermal efficiency in nuclear plants, then uranium demand would rise to 320,000 tonnes per year, and the R/P ratio would be 12.5 years.
30. The limited nature of the uranium resource has a very clear implication: If the world increased its nuclear capacity by five times, in order to displace the use of fossil fuels or forestall the effects of Peak Oil/Peak Gas, none of the hypothetical new reactors built in the UK would reach the end of their design lifetime before the world's proven uranium resource was exhausted. This problem was highlighted at the beginning of the commercial nuclear industry, and was the catalyst behind Britain's early experimentation with fast reactors (see below), subsequently abandoned in the 1980s.
31. In relation to the use of nuclear energy to off-set the use of fossil fuels, recent research published by the OECD [OECD, 1999] suggests that there is insufficient uranium to make a significant impact on the use of fossil fuels unless fast breeder reactors are developed in the near future. It should also be noted that the longevity of uranium resources were not considered as part of the government's recent Energy White Paper [HMSO, 2003]. In fact, without any real analysis of the uranium resource issue, whilst outlining issues for the white paper, the Downing Street Performance and Innovation Unit described uranium as [PIU, 2002]:
"...plentiful, easy and cheap to store, and likely to remain cheap. This means that nuclear power is essentially an indigenous form of energy."
32. Clearly, the position of the PIU would only be valid if the entire uranium resource were usable, but that is not the case. Britain has a lot of uranium in storage, but it is depleted

uranium – ^{238}U – left over from uranium enrichment/fuel fabrication. In order to use the other 99% of the uranium resource we would have to successfully develop fast reactors, which fission ^{239}Pu whilst at the same time 'breeding' more ^{239}Pu from the unused ^{238}U . As yet, there is no commercially marketable fast breeder design, and the recent MIT study of the future of nuclear power [MIT, 2003] did not consider fast reactors to be a realistic prospect for a few decades. This is because, to date, the problems inherent in the design of fast reactors have hindered the development of a large-scale, usable prototype. The major nuclear power states – Britain, the USA, France, Germany and Japan – have all invested in fast reactor research programmes and today the only significant work on prototype designs is being carried out by India and Russia [WNA, 2005b].

Renewable Sources – capacity vs. spatial development

33. If fossil fuels and nuclear power have capacity problems due to the limited availability of fuel, then renewable resources should have a clear advantage. Being renewable, their energy sources are continually renewed by the natural environment. However, the limitation here is area required to intercept a sufficient 'flux' of energy in order to produce enough energy to meet our demand.
34. It is often said that we only use a minute fraction of the energy that the Earth receives from the Sun each year. Whilst factually true, these statements show a clear misunderstanding of the cycling of energy through the natural environment. The energy that the Earth receives from the Sun each year creates a specific energy environment within the Earth's biosphere. If we intercept more energy from the Sun, reducing the energy reflected back into space, then the Earth will get hotter (the amount of energy radiated by the planet sets up a thermal equilibrium that determines the global temperature). Likewise, if we intercept a greater proportion of the energy that goes into the hydrological cycle, or the other climate cycles, it will affect our weather and climate.
35. The human race already uses a very large quantity of energy. The 428 exa-Joules (EJ) of energy [BP, 2005] used in 2004 represents about half of the energy that could be produced by burning all the terrestrial biomass (plant matter) produced around the globe each year in conventional power plants. The reason we can use such a large amount of energy is because fossil fuels represent solar energy that was collected for millions of years, and which has been processed using geothermal heat for tens of millions of years to produce very dense sources of fuel (oil, gas and coal). In order to utilise renewable energy sources the first obstacle we must overcome is cutting our use of energy down to a level where renewable sources are a realistic option without restricting other important activities – such as food production – because of the amount of land which must be devoted to energy production.

36. The Sun radiates a fixed amount of energy onto the Earth, which varies according to latitude. Intercepting solar energy directly using solar heat or photovoltaic (PV) systems, or indirectly using biomass, is therefore limited according to the amount of land we are able to devote to collecting the Sun's radiation. Some advocates of renewable energy believe that certain countries around the world, because of their large land area, could become 'exporters' of renewable energy – principally biomass or vegetable oils. However, given the problems created by climate change, and the global erosion of the agricultural land resource [UNEP, 2002], I do not believe that this is a realistic issue.
37. The production of energy from biomass is a good example. Southern England receives, on average, 36,000 giga-Joules of energy per hectare per year (GJ/ha/yr) [OU, 2004]. Of this figure, on average, only 5% (1,836GJ/ha/yr) of this energy will actually be absorbed by the plant, and only 0.6%, or 230GJ/ha/yr, will be converted into usable biomass. Depending on the form of combustion used, the moisture content, and the amount of energy used for harvesting and transport, the net energy production might be as little as 10% of the energy contained in the biomass (23GJ/ha), which in terms of electricity is about 6.4 mega-Watt-hours per hectare per year (MWh/ha/year). Given that in 2004 the UK's power consumption was 400,000,000MWh, it would require 62.5 million hectares of land to produce the UK's electricity demand – which is about 2.5 times the UK's total land area.
38. The production of biodiesel is equally restricted. Using figures from a DEFRA sponsored study [Hallam, 2003], one hectare of intensively grown oilseed rape can produce 3.1 tonnes of seed, which will yield biodiesel with a calorific value of 41.4GJ/ha/yr. Assuming a fuel consumption equivalent to 45 miles per gallon, a diesel car would require 0.85 hectares of land to fuel it for the average 9,000 miles travelled each year. Consequently, producing biodiesel for the 30 million cars registered on the UK's roads would require about 25 million hectares of land, which is slightly larger than the UK's total land area.
39. Wind power, tidal power and water power are more dense sources of renewable energy, but these too are limited. However, these limitations are being made worse by the manner in which they are being developed. In order to connect economically to the national grid, and in order to maximise the return on investment, renewable energy projects are becoming far larger than they need to be. Instead of diffusely collecting energy from many sites, government policy is concentrating development, using large scale engineering, on a small number of sites. As a result these developments have received a greater level of opposition from the public.
40. Wind power is a good example of how the target of 'industrial scale' energy production is wastefully using land, and creating a public backlash against renewable energy in the process. The larger the wind turbine, the further apart they must be spaced within wind

farms, and consequently the lower the energy yield per hectare of land. Working theoretically, a large wind 2.3MW turbine (such as a Nordic N90 turbine) spaced five hub heights apart (an average separation distance) from other turbines has a capacity of 108 kiloWatts per hectare (kW/ha). However three 850kW turbines (such the Vestas V52) would occupy the same area of land, and even though they are 40% shorter they produce more power – 111kW/ha (note, this figure includes a weighting that reflects the V52's lower height). The reason that wind farm developers are building ever larger turbines is quite simple: Whilst capital costs can be discounted over future years, maintenance costs are always at the present value. Consequently the development of fewer, larger turbines increases the power output whilst reducing maintenance costs – increasing the return on the capital invested.

41. Taking the 111kW/ha figure as a representative energy density for wind, to match the UK's major electricity generators 73,308 mega-Watts (MW) of net installed capacity [DUKES, 2005g], and assuming that the turbines generated for 30% of the time and that an additional 40% of capacity was required to charge batteries/fuel cells to provide a continuous power output, just over 3,000,000 hectares of turbines would be required – equivalent to around 13% of the UK's land area. Theoretically then, we could generate our power requirements from wind turbines. But, as noted above, electricity is less than one-fifth of the UK's total energy consumption, so this solution this would only answers a small part of the UK's energy problem – for a total solution we'd have to densely cover half the UK's land area in wind turbines.
42. The first stage in the process of developing truly sustainable energy resources within the UK would be to decentralise the national grid. This would allow a greater proportion of our energy demand to be met from local sources, which in turn allows for a greater diversity of efficient generation (e.g., combined heat and power) and renewable energy sources to be developed. Such an option was outlined by the Parliamentary Office of Science and Technology in their report on UK Electricity Networks [POST, 2001]. Some campaign groups are also supporting initiatives to enable a greater decentralisation of the UK's energy supply [GPeach, 2005]. Decentralising the grid would mean that the generating capacity of individual generating plants would fall, however the greater opportunity for the development of combined heat and power systems would mean that the efficiency with which we utilise fuel sources could rise from the current 40% to 60% or higher. Such a system would also allow embedded storage systems to be employed, and this would mean that smaller and intermittent renewable energy sources could have their output buffered in order to meet the peaks in local energy demand.
43. To ensure our future energy security we should look within our own borders to meet our energy needs. Across all sources, it's possible to produce around 40% of our current energy demand from renewable energy sources. Consequently, we need to cut energy use by 60%. This is, using current technologies, achievable – for example, in the

domestic sector we can look to Oxford University's recent work on energy efficient housing [OXECl, 2005]. However, when evaluating the costs of this transition, it would be wrong to use current prices as a baseline. Realistically, Peak Oil will mean that energy prices could rise 10%, year-on-year, for one or two decades – until a new equilibrium develops between the availability of energy resources and our demand for energy. For this reason we cannot value the future energy prices in terms of those today. Instead we should price various strategies in terms of certain energy and economic indicators, based at fixed points in the future, in order to provide a relative comparison.

Conclusion – the need to significantly cut energy demand

44. The UK has an energy problem... we use too much. As we enter an era of declining energy we must recognise and address this fact in the shortest possible time-scale.
45. Rather than focusing on building new capacity, the Committee should investigate the development of 'negative capacity', or using the phrase coined by the Rocky Mountain Institute, *nega-Watts* [RMI, 1990]. We face a very simple choice. We cut our energy consumption, displacing demand through renewable sources and cutting energy use, or progressively higher energy prices over the next two to three decades will cause immense damage to our national well-being.
46. Peak Oil, perhaps as soon as 2007, is going to make oil prices rise far further than their current historically high levels. Between 2020 and 2030, Peak Gas will make the overall energy situation even worse – especially if current trends continue and we are dependent upon natural gas for much of our energy requirements by that time. As a country, which is now in the process of becoming a net energy importer of oil and gas due to the peaking of our own oil and gas reserves, building more generating capacity will mean that over the coming years a greater proportion of our national wealth will flow out of the country.
47. The alternative is, logically, simple – we cut energy demand significantly in order to meet more of our requirements from within our own borders. This will be more expensive in the short-term, but unless we adopt such a course of action soon the economic damage wrought by a declining global economy, as global energy resources shrink, will make the process of transition far more unpleasant.
48. The Committee must not narrowly focus on electricity. Electricity is less than one-fifth of the UK's energy consumption, and the problems facing the generating industry today will be replicated in other sectors within a decade or so due to the effects of Peak Oil. Likewise, some of the renewable sources better suited to the domestic and commercial environment produce heat, not power. Therefore the Committee must look at measures

across all energy sources that will manage energy demand.

49. Nuclear power, quite apart from the environmental and safety objections, has a fundamental limitation on its use imposed by the thermal reactor system. Expanding our nuclear capacity in order to off-set the use of fossil fuels will, if replicated around the globe, shorten the already brief lifetime of the uranium resource by the same proportion. The projections by the nuclear industry, and by inference the government's own white paper on energy, assume that fast reactors will be available to use the depleted uranium produced by the thermal reactor cycle. However (rather like fusion reactors) there is no realistic prospect that this will happen in the near future.
50. Renewable sources of energy produce less power compared to conventional energy sources because of the land area they require. However, in an era where all conventional energy sources will go into decline, there are few other options. Therefore, if we are to develop truly sustainable renewable energy sources, we must match our energy demand to the amount of power that renewable energy sources can develop.
51. Adapting to a low energy economy would require, over the course of the next 60 to 80 years, that we evolve a wholly new economic paradigm. This may sound incredible, or unachievable, but it has happened before. During the 18th Century the UK experienced a comparable change in its social and economic organisation with the coming of the Industrial Revolution (and still, today, we use the inefficient steam turbines and power generators developed during this era). This Industrial Revolution marked the transition, within a few decades, to a society that progressed through an ever-higher level of energy consumption. Cutting energy demand by 60% will require a 'post-industrialisation', as we use modern technologies to cut energy demand, and decentralise many of the energy intensive systems that were built up over the course of industrialisation. In order to adapt to a contracting global energy supply over the next century, our future well-being must be linked to our capacity to use *less* energy.

END

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Sources

Note – the various web addresses given in this section were correct as of 15th September 2005.

- BP, 2005 *Putting Energy In The Spotlight – The BP Statistical Review of World Energy 2005*, BP, 2005.
http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/publications/energy_reviews_2005/STAGING/local_assets/downloads/pdf/statistical_review_of_world_energy_full_report_2005.pdf
- Chapman, 1975 *Fuel's Paradise – Energy Options for Britain*, Peter Chapman, Penguin Books, 1975.
- DUKES, 2005a Chapter 1 – *Energy*, Digest of UK Energy Statistics, DTI 2005.
<http://www.dti.gov.uk/energy/inform/dukes/dukes2005/01main.pdf>
- DUKES, 2005b Table 5.10 – *Plant Loads, Demand and Efficiency*, Digest of UK Energy Statistics, DTI 2005.
http://www.dti.gov.uk/energy/inform/energy_stats/electricity/dukes05_5_10.xls
- DUKES, 2005c Table 1.1.1 – *Inland consumption of primary fuels and equivalents*, Digest of UK Energy Statistics, DTI 2005.
http://www.dti.gov.uk/energy/inform/energy_stats/total_energy/dukes2005_1_1_1.xls
- DUKES, 2005d Table 5.4 – *Fuels Used in Generation*, Digest of UK Energy Statistics, DTI 2005.
http://www.dti.gov.uk/energy/inform/energy_stats/electricity/dukes05_5_4.xls
- DUKES 2005e Table 5.6 – *Electricity Fuel Use, Generation and Supply*, Digest of UK Energy Statistics, DTI 2005.
http://www.dti.gov.uk/energy/inform/energy_stats/electricity/dukes05_5_6.xls
- DUKES, 2005f Table 1.1 – *Aggregate Energy Balances*, Digest of UK Energy Statistics, DTI 2005.
http://www.dti.gov.uk/energy/inform/energy_stats/total_energy/dukes05_1_1-1_3.xls
- DUKES, 2005g Table 5.7, *Plant Capacity – United Kingdom*, Digest of UK Energy Statistics, DTI 2005.
http://www.dti.gov.uk/energy/inform/energy_stats/electricity/dukes05_5_7.xls
- DUKES, 2005h Table 7.1 – *Commodity Balances 2004*, Digest of UK Energy Statistics, DTI 2005.
http://www.dti.gov.uk/energy/inform/energy_stats/renewables/dukes05_7_1-7_3.xls
- DTI, 2005a *UK Energy in Brief July 2005*, DTI 2005.
http://www.dti.gov.uk/energy/inform/energy_in_brief/energyinbrief2005.pdf
- EC, 2001 *Energy Green Paper, Towards a European Strategy for the Security of Energy Supply*, European Commission 2001.
http://europa.eu.int/comm/energy_transport/doc-principal/pubfinal_en.pdf

- GPeace, 2005 *Decentralising Power – An Energy Revolution for the 21st Century*, Greenpeace, July 2005. <http://www.greenpeace.org.uk/MultimediaFiles/Live/FullReport/7154.pdf>
- Hallam, 2003 *Evaluation of the Comparative Energy, global Warming, Socio-Economic Costs and Benefits of Biodiesel*, School of Environment and Development, Sheffield Hallam University under contract from the Department of Environment, Food and Rural Affairs, January 2003. http://www.shu.ac.uk/rru/projects/biodiesel_evaluation.html
- HMSO, 2003 *Our Energy Future: Creating a Low Carbon Economy* (Cm5761), HMSO 2003. <http://www.dti.gov.uk/energy/whitepaper/index.shtml>
- IEA, 2002 *World Energy Outlook 2001 – 2001 Insights*, International Energy Agency (IEA) and the Organisation for Economic Co-operation and Development (OECD) 2001. http://library.iea.org/dbtw-wpd/Textbase/npold/npold_pdf/weo2001.pdf
- MIT, 2003 *The Future of Nuclear Power: An Interdisciplinary MIT Study*, Massachusetts Institute of Technology, 2003. <http://web.mit.edu/nuclearpower/>
- Mobbs, 2005 *Energy Beyond Oil*, Paul Mobbs, Matador Books, 2005. Further information on the book is available via the web site at <http://www.fraw.org.uk/ebo/>
- NGT, 2005 *NGT's Preliminary Winter Outlook Report – 2005/06*, National Grid Transco, 31st May 2005. http://www.ofgem.gov.uk/temp/ofgem/cache/cmsattach/11582_14405.pdf?wtfrom=/ofgem/work/index.jsp§ion=/areasofwork/securityofsupply
- OECD, 1999 *Towards a Sustainable Energy Future*, Dieter M. Imboden (Swiss Federal Institute of Technology) and Carlo C. Jaeger (Swiss Federal institute of Environmental Science and Technology) – published in *Energy: The Next Fifty Years*, OECD, 1999. <http://www.oecd.org/dataoecd/37/55/17738498.pdf>
- OIES, 2005 *Uranium Supply and the Nuclear Option*, Paul Mobbs, *OIES Energy Forum*, no.61, Oxford Institute for Energy Studies, May 2005. A fully referenced version of this article is available at http://www.fraw.org.uk/mobbsey/papers/oies_article.html
- OU, 2004 *Renewable Energy – Power for a Sustainable Future*, edited by Godfrey Boyle, The Open University, Oxford University Press, 2004. <http://eeru.open.ac.uk/index.htm>
- OXECI, 2005 *The 40% House*, Oxford University Environmental Change Institute, 2005. <http://www.eci.ox.ac.uk/lowercf/40house.html>
- PIU, 2002 *The Energy Review*, Downing Street Performance and Innovation Unit Report, February 2002. <http://www.number-10.gov.uk/su/energy/1.html>
- Price, 2002 *Nuclear fuel resources: Enough to last?*, R. Price, J.R. Blaise, NEA Updates No. 20.2, OECD-NEA 2002. http://www.nea.fr/html/pub/newsletter/2002/20-2-Nuclear_fuel_resources.pdf
- POST, 2001 *UK Electricity Networks*, POST Note No.163, Parliamentary Office of Science and Technology, October 2001. <http://www.parliament.uk/post/pn163.pdf>

- POST, 2004 *The Future of UK Gas Supplies*, POST Note No.230, Parliamentary Office of Science and Technology, October 2004.
<http://www.parliament.uk/documents/upload/POSTpn230.pdf>
- RIIA, 2004 *Turning the World Upside Down*, Paul Mobbs, *The World Today*, vol.60 no.12 (p.16), Royal Institute for International Affairs (Chatham House), December 2004. A version of this article, published under the original title Energy Beyond Oil, is available at http://www.fraw.org.uk/mobbsey/papers/ebo_article.html
- RMI, 1990 *The NegaWatt Revolution (E90-20)*, Amory Lovins, Rocky Mountain Institute – published in *Across the Board*, September 1990.
http://www.rmi.org/images/other/Energy/E90-20_NegawattRevolution.pdf
- Times, 2005 *Uranium Shortage Poses Threat*, Angela Johnson, The Times, 15th August 2005. <http://business.timesonline.co.uk/article/0,,9069-1735134,00.html>
- UNEP, 2002 *Global Environmental Outlook 3*, United Nations Development Programme, 2002 (published by Earthscan Books).
- USEIA, 2005 Table 3, *International Petroleum Supply and Demand: Base Case – Short Term Energy Outlook*, US Energy Information Administration, August 2005.
<http://www.eia.doe.gov/emeu/steo/pub/3tab.pdf>
- WNA, 2005a *Energy Analysis of Power Systems*, WNA Issue Briefs No.11, World Nuclear Association, August 2005.
<http://www.world-nuclear.org/info/inf11.htm>
- WNA 2005b *Fast Neutron Reactors*, WNA Issue Briefs No.98, World Nuclear Association, September 2005.
<http://www.world-nuclear.org/info/inf98.htm>