# ELECTRICITY:
# THE FULL COSTS OF COMPLETE SYSTEMS

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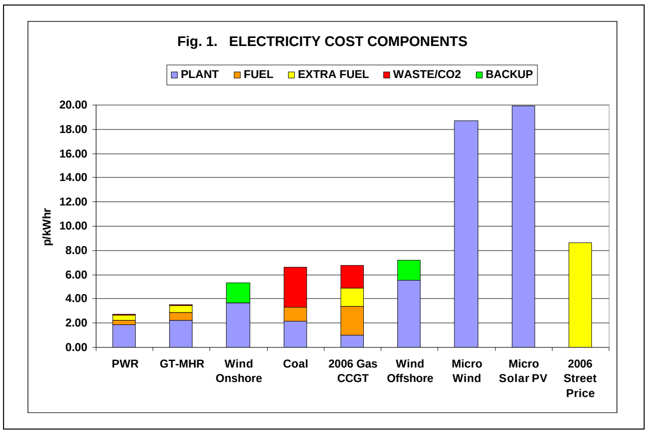


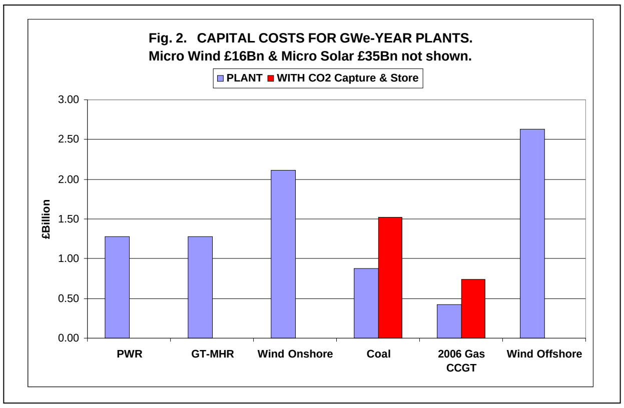


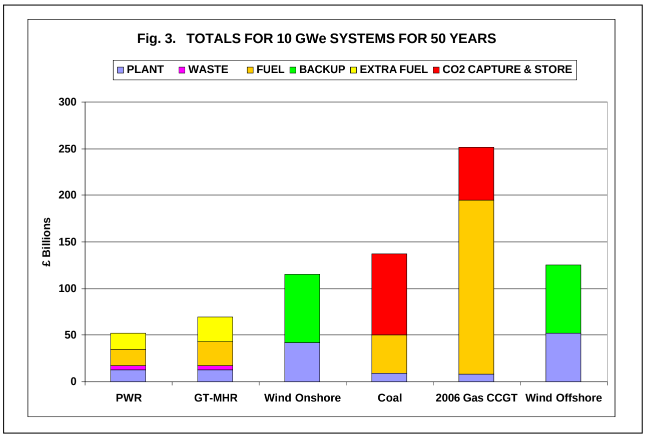


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## Executive Summary

The UK Departments of Trade & Industry and of Environment (DTI & DEFRA) have published the conclusions of their 2006 Energy Review, starting the process to issue a White Paper on replacements for our aging energy infrastructure. Unfortunately, they have not published any of the vast amount of written and oral evidence collected in the Public Consultation process. Fortunately, the UK House of Commons Environmental Audit Committee (EAC) published a report of their own review, called 'Keeping the Lights On: Nuclear, Renewables, and Climate Change' in April 2006. This is a collection of views quite representative of the spectrum of DTI-DEFRA evidence.

The 'Energy Challenge' report gives a rational assessment of the situation but, as a political document, is unable to go further than public or political opinion permits. This work is not so constrained.

Here we focus on a single issue: In three charts, we give a comparison of the unit costs for each electrical energy system, the costs of delivering a Gigawatt-year of electrical energy ( a million kilowatt hours, every hour, for a year is 1 GWe-yr) , and the lifetime cost of a complete 10 GWe-yr system over a 50 year timescale. The estimates on which these are based were found by backtracking all the references in the EAC evidence, by updating the 2003 numbers for fuel costs to those published in 2006, and by using recent reports like the new Intergovernmental Panel on Climate Change (IPCC) report, not then publicly available to EAC. That is to say, I have used the exact same data as that referred to frequently in the EAC review. All the results of this simple arithmetic can be readily checked.

1. **Rooftop Micro-power.** Solar PV and Wind based micro-power <u>in the UK</u> cannot compete with central power generation and will not recover their initial investments.
2. **Wind power** is the most competitive renewable energy source but new transmission lines, grid controls, and intermittent industries or new energy storage mechanisms are needed to take full advantage of it.
3. **Gas is the Most Expensive Long Term Option.** Electricity from gas will definitely be the most expensive option over a 50 year timescale. It will have to be abandoned as a principal (>25%) energy source after 2030.
4. **Carbon capture and storage**, (CCS) using the IPCC numbers, seems far too expensive <u>for the UK</u>, the best option being to phase out coal as soon as possible in favour of nuclear power.
5. **CCS & Extended Oil Recovery**. This is a possible way to fund the CCS infrastructure.
6. **Nuclear Power** is already the cheapest electricity source in p/kWh or by long term costs and offers the greatest security of supply.

The Energy reviews, and the work of the Committee on Radioactive Waste Management (CORWM) have been conducted with a technological time horizon of little more than a decade in the search for instant answers. Fossil fuels are in the last stage of any technical improvement and are responsible for the threat of huge climate change. By 2050 the world will be very different and the nuclear industry, for one, will be deploying the fruits of current research and development. The technical pathway to a stable climate and a successful position for humanity by 2100 needs public support and understanding. A number of the most important topics are briefly addressed here, including:

- **Spent nuclear fuel is still fuel.** Spent fuel and depleted Uranium will become an enormously valuable fuel resource by 2050, allowing our French operators to run the UK's advanced reactor fleet for hundreds of years, quite independently of other Uranium sources.
- **Nuclear Problems Solved**. Generation III+ reactors are ready for final demonstrations to be built. Generation IV nuclear reactors, including Thorium based systems, should be ready for demonstration by 2030.
- **Energy Research**. The UK should make its contributions to a very strong EU programme of research into all new energy sources throughout this century.

The details of the calculations behind the three comparison charts are given in the body of this paper.

## I. Key Issues for Energy Policy

An overriding consideration in predicting our energy future has become the modelling of the rapid impact of our greenhouse gas emissions, in particular $CO_2$, on global warming and possibly irreversible climate change. This would be eventually catastrophic for human civilisation and so a political goal has been set to reduce global emissions by 60% by 2050.

The fact that the planet is not suffering an ice age is not a proof that global warming, at the obviously very fast rate of present warming, is driven by natural processes over which we have no control. The geological warming and cooling periods have been well matched with the computed variations in the orbit and inclination of the earth induced by the gravitational effects of the big planets, Jupiter, Saturn, and Neptune, while the sun itself has maintained a steady output for over a million years. We are now in a long stable period and the next ice age is estimated to be 50,000 years away. Thus, orbital changes do not explain the temperature changes over the last century or the rapid rise in the last 25 years. The weight of $CO_2$ in the atmosphere is about 0.037%, adjusted to this tiny level by our biosphere, and so is easily changed by industrial scale technologies. The problem of extraordinary global warming is very serious and, being caused by our own technologies, is amenable to technical solutions if we act with determination.

However, no energy or economic modellers have taken account of the fact that our oil and gas supplies will peak and decline within the next 30 years, while many oil analysts predict 2010-2015 for the peak of cheap oil (Campbell). This will have huge economic consequences less than halfway into the lifetime of the next tranche of gas fired power stations. The EAC evidence shows that the DTI modelling predictions for oil and gas markets between 2001 and 2005 have been completely wrong and prices are even out of the range of variations they considered.

The second set of big events which will influence the future are the substantial strides made in the research & design of new nuclear reactors beyond the Westinghouse and EdF replacements for the old UK reactors. Some of these can run solely on the high level, long lived waste from the 20th century reactors, burning most of it by 2050. Reprocessing spent fuel for re-use will allow us to run 10,000 reactors for 1000 years. Nuclear power based on Thorium can extend this for another 1000 years or more.

Opponents of nuclear power are fighting old battles which have already been won in the nuclear laboratories of France, Japan, Russia, and the USA. Other energy sources will also benefit from vigorous R&D programmes within the EU.

None of these nuclear developments were discussed in the EAC review by government, academia, or industry in a mistaken belief that more information would only confuse the public.

The third set of big events which will affect our energy future are all derived from our failure to respond adequately to global poverty or to acknowledge it as a driver of social unrest.

It would be hopelessly wrong for us to imagine that short term energy decisions made now, based on the Energy Review process, will secure our future even till 2020. We need a much more robust approach which will continually open up new options and build strongly on the most successful results.

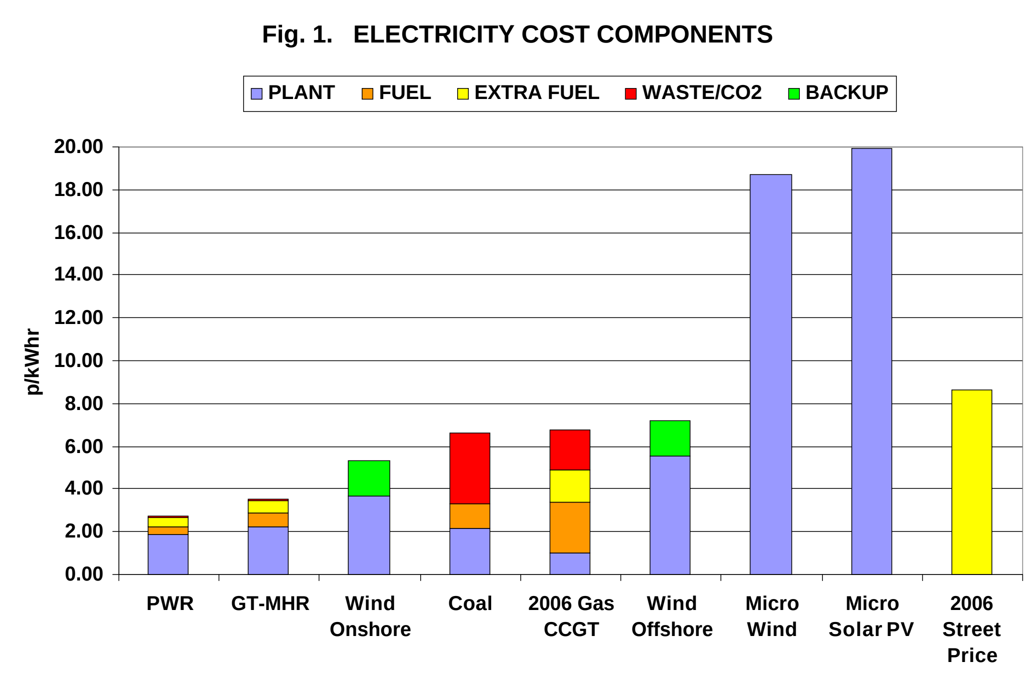
Predictions of doom must be seen just as warnings of avoidable futures. Let us see how some simple arithmetic, based on published data, can guide our choices.

## II. Pricing a Kilowatt Hour

Our electricity bills are priced in pence per kilowatt hours (p/kWh) consumed. A typical quarterly household bill would be about 3500 kWh/year at a current price of 8.6 p/kWh – the “street price” which includes all services, profits, and taxes. A typical natural gas consumption for hot water and central heating in a well insulated home is for 30,000 kWh at 2.4 p/kWh, a price which could well be 5p/kWh by 2010. The annual energy bill is therefore about £1021 and rising. The electricity will run a hundred different appliances and gadgets in a home while the gas runs one – the furnace – reflecting the huge importance electrical energy plays in our lives. Conservation, cold showers, and woollen sweaters are becoming important. In energy efficient homes, doing without is the final conservation option.

The charge rate of p/kWh conceals everything about the means of supplying this energy and the scale of national expense needed to secure it. At the very least we should understand how it is broken up into capital, fuel, waste disposal, and any other special costs for all the energy sources we are asked to use.

Here is a chart for the eight energy systems we will consider and the current street price consumers pay:




Let us begin with the obvious highlights …

The base costs are for the capital cost of plant or equipment plus Operations and Maintenance and Management, and for the fuel, if any. The capital cost numbers then used by RAE to compute the p/kWh also include interest at 7.5% over a 20 year period. To compute the cost of electricity, the total cost is divided by the expected number of kWh generated in this period.

The fuel cost for natural gas has been increased to reflect the price increase in 2006 over the price used in the 2003 RAE report. Electricity from gas is already more expensive than from coal, though the capital cost is still the lowest of all.

The Micro power sources for individual homes lose all large scale benefits and are far more expensive than electricity from any grid source. The savings on grid electricity are too small to recover their costs within their engineering lifetimes.

Waste disposal is seen as a major problem for nuclear power. However, the new designs on which the above figures are based are designed to be easily serviced and dismantled. Disposal of the high level wastes in the fuel rods of a Pressurised Water Reactor (PWR) like the Westinghouse AP1000 or the larger European Pressurised water Reactor (EPR) is estimated at 0.1p/kWh over their 50+ year lifetime, and barely shows up on the chart. The cost of capture and storage of from coal and gas stations is a different category and could make coal as expensive in the UK as Offshore Wind.

Let us now discuss the detail behind each source, starting with the most expensive. This is not an attempt to discredit or promote any particular technology, but merely a cold evaluation of the facts and numbers which emerged from the EAC evidence.

## *II.1 Micro Solar Photovoltaics*

Solar power is clean, green, and desirable but ludicrously expensive in the UK as a source of power. Few proponents of Solar PV ever give a cost in p/kWh for this reason. Even so, it is getting close to competitive in very sunny places. In England it does have many excellent niche applications.

An Oxford study (Jardine et al) of 11 sets of Solar Panels found that the top performers, like the Siemens ST-40 panel, using a copper-indium-diselenide as the most efficient collector for the UK, produced 1004 kWh/year per kW-peak rating in Oxford and 1590 kWh/year/kWp in Mallorca. There are 8760 hours in a year. Sometimes the panels output their rated power, but most of the time they output nothing. Despite this, Solar PV and other intermittent sources are always quoted by their rated or peak power output which is rarely achieved.

The Clean Skies website, run for the government's renewable energy programme, gives the installed price of a Solar PV rooftop system as £4000-6000/kWp, depending on the rooftop. Taking the low figure and dividing by the total lifetime output we get an average cost of 19.9p/kWh (blue), or 30p/kWh for a more expensive installation. At this price and an 8.6p/kWh rate for mains electricity, the system will never recoup its investment in its lifetime. There are no interest charges on your cash payment for the system, but you may expect to pay £25/year for maintenance. The DTI's Micropower Council carefully omits any cost evaluation of Solar PV in its EAC submission.

There is some discussion of 'Smart Meters' which could feed these puny amounts of power back to the grid when they cannot be used immediately. This just glosses over the fact that there is a whole family of missing appliances, controls, and storage methods yet to be developed to get the best use out of Solar power anywhere.

At an industrial scale above 100kWp the cost of the PV panels is about half the domestic cost, putting Solar PV somewhere above Offshore Wind as an energy source. However, no power company is proposing to build any such plants in the UK.

There is a continued hope that better PV materials will be found which are much more efficient and cheaper to manufacture. This goal has been vigorously pursued in US, Japanese, and EU laboratories for over 30 years and the Siemens ST-40 represents the best of what has been achieved. The research has now plateaued with no significant progress in the last decade. There is always hope but that is not a business plan or a policy.

## II.2 Micro Wind Power

The story for small wind turbines to be mounted on rooftops is quite similar. Small 1-2kWp turbines are just coming onto the market and Windsave (www.windsave.com) is typical. The installed cost of £1874 seems modest for a 1kWp windmill. However, a typical annual output is about 1000 kWh, which is also 1 megawatt-hour, which sounds bigger. Advertised life expectancy is 10 years so the average electricity cost is 18.7p/kWh and even this small investment can not be recovered. At most 1/3$^{rd}$ of a windy household's annual electricity bill may be saved, but the total electricity cost goes up by £50 per year. The Micropower Council claimed 4.63p/kWh in 2004 before actual equipment was available.

The Windsave system currently runs only when the wind is blowing AND some appliance in the home is switched on. This is clearly a fatal flaw which will doubtless be fixed for later systems.

More serious is the fact that very few UK cities are built in windy areas so wide deployment is simply not workable. However, there are many windy country farms which always need to pump water or run equipment and get the full benefit of such systems.

Despite the costs many people will be persuaded that micro-power is somehow worthwhile. After all, isn't paying a few more pennies per kWh worth it for the emissions saved? Small government grants may seem to be an incentive but they will already have been absorbed in the vendor's pricing structures and are actually a subsidy to the industry, not the consumer. Regrettably, the numbers show that investment in micro-power for the UK is in fact an enormous waste of the public's money.

### II.3 Commercial Wind Power

This is a technology based on a century of design of electric motors and generators and the arts of engineering towers and large propellers. Because they are installed in the open to contend with all weathers the windmill lifetimes are only rated for 25 years. A key element is that ambient wind speeds are greater and more constant above 25 metres from ground level. This is even better offshore since the sea interferes far less with the wind flows than does a variable landscape, though the marine engineering requirements increase the cost by about 50%. Current windmill designs run best at speeds of 10 m/sec. over a range of 8-15 m/sec. Needless to say, areas with such high wind speeds are mostly far from heavily populated areas and so new, long distance transmission lines are needed. This is fortunate since wind farms require huge areas for their windmills. Additional costs for this are not included in Figure 1.

What is included is the RAE cost for backup power, like gas fired turbines, to replace the output when the wind has dropped, or reached storm conditions in which the windmills abruptly shut down while the demand is still high. Conversely, the windmills may have to be shut down and the energy discarded if there is insufficient demand. Denmark has some of the largest wind farms in Europe and maximises its output by exporting it to a very large market including neighbours like Germany and Norway. The UK does not have that option.

## II.4 Coal and Gas

The 2003 RAE report estimated the fuel cost (orange) for Closed Cycle Gas Turbine power at 1.53 p/kWh. All forward planning for the next 30 years by all energy agencies in the US and the EU have held fast to the idea that gas prices will remain this way for the foreseeable future and that oil would remain at £20/barrel forever. The predictions completely ignored the obvious rise of Chinese and Indian economies and the imminent peak of cheap oil supply. Gas easily turned out to be the cheapest power source, especially since a power station is just a direct connection between gas supply and the turbines, making the capital investment the lowest of all. The recent price increases have had market driven spikes but the new averages are far above $20/barrel and 20p/therm are permanent and will rise further. At 270p/therm gas fired electricity would cost the same as Solar PV in the UK.

The RAE measure for fuel cost has therefore been raised in proportion to the new 2006 average price of 33p/therm for gas – not the high peaks of last winter, or the August rate of 60/therm - to 2.52 p/kWh. This promptly makes gas more expensive than Coal and Nuclear and just below Onshore Wind power. Figure 1 also makes an allowance (yellow) for further price increases in gas and in nuclear fuel over the next 20 years.

The next consideration is $CO_2$ emissions. Coal and Gas globally produce over 1 billion tonnes a year of this greenhouse gas which accumulates in the atmosphere and will take 500 years for the biosphere to recapture it. There are only two sensible proposals for dealing with this: (a) Stop using Coal and Gas or (b) Capture and safely store all the $CO_2$ waste in deep geological depositories (CCS).

Note that this is not 'Clean Coal' which, as advertised, is merely the capture of particles, Sulphur, and other pollutants, leaving the most dangerous waste of all, $CO_2$, to be discharged.

There were no good cost estimates publicly available at the time of the EAC or DTI reviews – though the results were available internally. The Intergovernmental Panel on Climate Change (IPCC) has now published its report which includes a detailed study of CCS technology. It takes energy to capture the $CO_2$ and pump it onto a national $CO_2$ grid for deposit in the North Sea oil fields. The UK is densely populated and so a grid will be very expensive, at £1.1/tonne/100 miles/year, with many detours, pumping stations, and so on. Ocean burial, at £18/tonne, is the most expensive option and the North Sea probably the worst environment in which to do it. We have therefore shown the top end of the IPCC estimates at 1.9 p/kWh for gas and 3.29 p/kWh for coal, almost double the low end estimates which are what the USA and China would have to fund.

The required technologies have been demonstrated in several places but it will still take 20 years to actually build all that infrastructure and have a fully operational CCS system for the UK. By that time it will be quite apparent that coal and gas are indeed the most expensive energy options available and getting worse.

There may be some relief to be had by using some of the $CO_2$ for Enhanced Oil Recovery (Hugh Sharman, http://ior.rml.co.uk/issue4/co2/inco2/summary.htm). By pressurising depleted oilfields with $CO_2$, up to 3.3 barrels per tonne of $CO_2$ may be recovered. This can lift the total recovery from an oilfield by about 10%. In the case of the North Sea this would amount to a further 3 billion barrels over the next 20 years, capturing 1 billion tonnes of $CO_2$. With oil at £35-£45/barrel the oil companies could comfortably buy $CO_2$ .and build the pipeline infrastructure for an ongoing CCS system.

BP has the only onshore, UK, billion barrel oilfield in Poole, Dorset, with an 11km. long set of wells under the bay at Bournemouth. It is in decline and will need some EOR by 2015. This is a one off opportunity to build a 3GW clean coal power station in Poole and pump the $CO_2$ under the bay for about 50 years. This could yield an extra 100 million barrels of oil at £40+/b.

At least the gas stations are cheap enough that the next round to be built can simply be phased out in 25 years time. The coal stations would be a longer term investment and a European emissions trading scheme (ETS) might still allow them to continue to pollute. A global ETS to allow the US, China, and India to burn all the coal there is, without full CCS systems, would have little real effect on $CO_2$ emissions. The idea promoted to EAC that the UK could 'lead the way' with CCS technology is lugubrious since they need no such leadership.

The IPCC used the six standard economic models of energy growth and emissions in the 21st century. Only two could possibly hold atmospheric $CO_2$ below 500 parts per million: Growth with widespread use of advanced technologies – A1T, and economic recession and low growth – B2. Between war, the decline of oil and gas, and unresolved poverty, none of which are included in the models, B2 is the more likely outcome. For the technology path to succeed the best technologies must be pressed forward on an unprecedented scale. The UK government has rightly set Climate Change as a principal policy driver, but control cannot be achieved through unaffordable systems .

### *II.5 Nuclear Power*

The nuclear industry has been quietly working to solve all its technical problems of the 20th century. Despite the US-EU moratorium on building new reactors the industry has learned a great deal about safe, efficient operations, and about design of third generation systems which are far cheaper to build and to disassemble and decommission.

### II.5.1 Future Reactors

Although the US, the UK, and many other countries have largely dropped out of nuclear power research, the French, Japanese, and Russians have maintained vigorous programmes. The EAC and DTI reviews contain no discussion of the advanced systems (Generation III+ and Generation IV) which solve the remaining technical problems of nuclear power. For this reason, the General Atomics GT-MHR is included in our comparisons because it can run entirely on recycled waste from our old nuclear stations, burn up all the legacy of high level radioactive fuel wastes, be completely safe against loss of coolant events, and be 45% more efficient than PWRs.

The only comment on future nuclear technologies in the EAC review was from Sir David King, Chief Scientific Advisor:

‘Widespread use of fast breeder reactor technology could increase the utilisation of uranium sixty-fold or more.’

The comment went unnoticed in the EAC Executive Summary, and Sir David’s comments on the use of stockpiled Plutonium for electricity generation were dismissed. They chose instead to support the spurious work on $CO_2$ emissions from nuclear power (see McNamara, Opposition…) and other weakly researched reports on Uranium supplies.

### II.5.2 Spent Fuel is not Waste.

Advanced reactor and fuel developments were removed from consideration at an early stage of the study by the Committee on Radioactive Waste Management (CORWM) which therefore can now only recommend deep burial of everything. The recommendation is also for early closure of the repository, including back filling of stores as they are filled. The ideas that spent fuel is still fuel, or that depleted Uranium is fuel, appears throughout their report as an unlikely afterthought. This long, costly, laborious consultation process declared;

‘There was insufficient time in the programme to commission new original research.’

Fortunately, the burial process is long, with many stages. Many of CORWM’s conclusions will probably be overturned by 2030.

It is likely that our new reactors will be French and that they will manufacture the fuel, as is planned for Finland. When recycling starts for GT-MHR type reactors the French would be able to reprocess the spent fuel for the steadily increasing fleet of reactors in the EU. Hopefully, no fuel rods will have been concreted away and will still be available for re-use in the 2030-2050 time frame. Local French fuel factory and storage facilities may be needed to minimise the transport problems. The final high level waste to be buried will be one tenth of the currently planned volume, will generate even less heat in storage, and will decay to a natural background radiation level in a few hundred years.

Finally, we note how CORWM has muddled the numbers to achieve the maximum effect for their proposals. The 5 Albert Halls story is for present and future wastes, only 2% of which contains 92% of the radioactivity, a tiny volume at present of 20x20x20 metres – though you would not want to pile it up like that. The media love the 5 Albert Halls and muddle the numbers further.

### II.5.3 Nuclear Plant Costs

We show the GT-MHR as slightly more expensive than the new PWRs , though GA would claim it will be cheaper. Similar reactors are in operation in Japan and China and a weapons Plutonium burner is to be built in Russia, so these reactors should become widely deployable from about 2020. Further details were given in my submissions to the DTI Energy Review (McNamara).

The RAE Plant costs quoted here include decommissioning but not high level waste disposal. British Energy expect to pay into some government waste fund about 0.1p/kWh, or about £500 million per reactor over a 50 year timescale. This is TINY compared with the CCS costs, even with the least expensive versions, because the total waste to be treated is about 10,000 tonnes per reactor in 50 years time.

Long before this, GT-MHRs or other systems will have been deployed which require continual treatment of all spent fuel to recover and utilise the vast energy content remaining. The government nuclear waste funds will have been diverted into this approach and a levy per kWh will be unnecessary. The new systems will also eliminate the problem of nuclear fuel supplies for thousands of years. An arbitrary 'Extra Fuel' cost has been added in Fig. 1. to take account of the additional processing.

### II.5.4 UK Nuclear History

The notorious Sizewell B event was a great environmentalist achievement in filibustering the government into delaying the project so long that applications to build the other 8 reactors were never made. The destruction of the British nuclear energy industry, and the elimination of nuclear engineering from our universities, was also set in train and has been completed this year, 2006, by the government sales of all remaining assets. The only vendors capable of building new nuclear stations in Britain are the French, the Japanese, and maybe the Americans who also no longer have a nuclear construction industry. The vendors clearly do not need financial assistance to enter the high priced UK market, as was strongly emphasised by the fine evidence from EdF to EAC, but they do need to be assured that licensing and planning will not be allowed to be challenged endlessly or that government departments will not be allowed to procrastinate and demand continual changes to internationally accepted designs. These vendors will not enter the market without such assurances and will not wait 14 years before walking away.

One other historical comment is worth making: The British reactor designs sought to use natural Uranium as the fuel, as did the Canadians, to avoid the huge expense of fuel enrichment. Since then diffusion enrichment has been replaced by the far cheaper centrifuge systems. The decision led to the Magnox reactors and later to the Advanced Gas cooled Reactors, the AGRs. These have turned out to be far less efficient and harder to maintain than the American Pressurised Water Reactors, the PWRs. Accepting a PWR at Sizewell was an admission that the UK natural Uranium reactors had come to the end of their engineering capability. The design, construction, and control systems for these reactors look quite antique by modern standards. The Generation III+ and Gen IV reactors are now designed on supercomputers which can model details of the many nuclear reactions which take place in a real reactor – the neutronics -, the hydraulics, and the materials problems, in 3D and time. Like a fly-by-wire airliner, the future reactors will be much easier – and therefore safer – to manage than the 20th. century plants.

### *II.6 The p/kWh Comparison.*

The DTI/DEFRA submissions found it necessary to firmly support the 2003 White Paper on Energy and to claim that little had changed since then and that its conclusions were still sound. The final Energy Challenge report is, of course, very different.

The figures we present included equivalent costings for micro-power, the cost of waste disposal for each source, and new information on fuel prices since 2003 which completely re-order the rankings. You may prefer other reports and data sources and choose to criticise the IPCC report and stand firm on a return to cheap energy costs, but this tide will not be rolled back.

A basic, unanswered economics question is 'what is the level of energy costs which leads inevitably to global recession?' If we can build electricity systems which can always deliver below 10p/kWhr then we expect to avoid that.

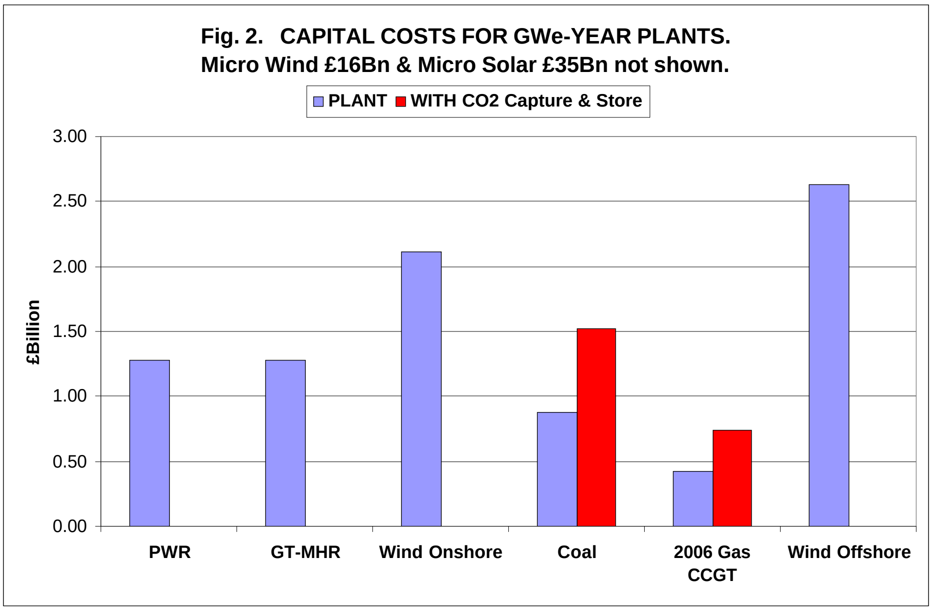
Despite the universal claim by activists to EAC that nuclear power is very expensive, when the full costs of each source are correctly measured, nuclear is the least expensive with onshore wind close behind. They deliver at under 6p/kWh.

The analysis is not complete. Pence is money in your pocket and a kilowatt hour will produce 10 pots of tea. Let us see what a complete electricity supply system really costs.

# III. Capital Costs per Gigawatt Year.

Cities and industries need billions of kilowatt hours. Large power plants can produce an average million kWh per hour – a Gigawatt – every hour of the year, a total of 8.76 billion kWh – a Gigawatt year.

Each energy source has a duty factor which limits its actual annual output. The Westinghouse AP1000 is rated at 1100 MWe so, at a duty factor of 90%, will deliver a Gigawatt year of electricity (GWe-yr). This is the duty factor currently achieved by many US nuclear stations, making their marginal cost of power production around 1c/kWh. Coal fired power stations face UK emissions restrictions and many Gigawatt size UK plants run at 1/3 of capacity.




Wind farms are always rated by their maximum capacity, which is almost never delivered, and their capital costs are quoted by their peak output, making them look extraordinarily cheap ( 1/3 of the values shown below.). The annual average duty factor is claimed to be 35% but Danish and German wind farms have not done better than 27%, partly because they have to be closed when the markets cannot absorb the power. We have used the 35% figure for comparisons and so a GWe-yr of wind power needs 3 GWe of installed capacity. The down side of this is that in some periods the system will actually be delivering 3 GWe and so the swings between peak, average, and shut down, which can happen in hours, are very large and difficult to handle on a grid. It has been recommended (Sharman) that UK Wind power should not exceed 10 GW-peak for this reason. It may be possible for some energy intensive industries to operate intermittently and use whatever excess wind power is available. The people of the island of Lewis, where the UK's largest wind farm is to be built, may also be able to operate a substantial industry in this way.

Rooftop Micro-power comes in at a miserable 11% and so a GWe-yr needs 9GWe installed and will never recover its investment. We had to drop micro-power from this chart as 1Gwe-yr would cost **£16.4 Bn** for micro-wind and **£34.9 Bn** for micro-solar. About 4.4 million homes would have to have installed an £8000-£12000, 2kWpeak system, about 4000 acres of Solar panels to provide 1GWe-year. Despite the enthusiasm from EAC, rooftop micro-power is just not a sensible or economic way to generate large amounts of electricity. We drop it from any further consideration.

To be practical we will only consider a 25 year period for capital and plant costs of an imminent round of new power sources, even though Coal and Nuclear plants are rated for 50-60 years.

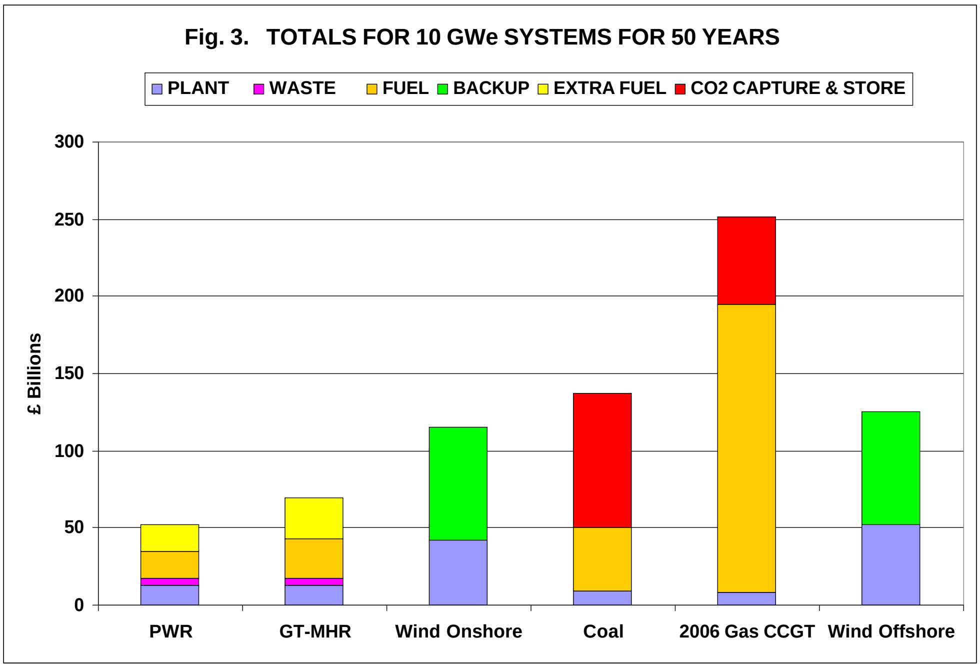
The capital costs for the various power sources shown in Fig. 2 and the rankings clearly favour gas, even with CCS. Commercially this would make for the best investment and quickest return on capital, but only if the price of Natural gas fuel had remained at 20p/therm. Since price rises can simply be passed on to the users the investment might still be safe if a global recession can be avoided.

It must be emphasised that no interest or discount rate on capital has been applied to these capital costs. The rates could be between 5% and 15%, depending on how much profit the investors can persuade us to yield to them in each case. Nuclear has been labelled as the riskiest investment but fossil fuel plants are clearly at high risk from punishing environmental controls and soaring fuel prices.

## IV. Total Costs of 10 GWe, 50 year Systems

The above costings only cover the equivalent of a single large power station. A complete system would be built in tranches of 10 GWe, along with their waste treatment and fuel supply facilities. We choose a 50 year time span to cover the lifetime of Coal and Nuclear stations and to run into and beyond the peak of oil and gas. This doubles the capital investment needed for Wind and Gas systems.

Another perspective is gained by calculating the value to consumers of a 10GWe system running for 50 years. At a street price of 10p/kWh the System income, including service and supply, would be £438 Bn.




For gas, the <u>conservatively</u> estimated price increases make gas the most expensive option of all. If we assume the latest date for the global peak of gas supply of 2036, then prices might be held stable at 33p/therm till 2026 as supplies continue to expand, even against a large rise in demand. This would be well after the peak of global oil, so markets would then understand what is to come. The price may double to 66p/therm as the peak is approached and go to 85p/therm after 2036. The 50 year fuel bill comes to £185Bn. If the price merely goes up steadily by 2.5 times over the next 50 years, the bill would be higher.

This simplistic calculation is not even a pretence at a global economic model but demonstrates clearly the great vulnerability of gas fired power stations to price rises. It seems highly likely that a no more gas fired power systems will be built after about 2030.

Backup for Wind power would most likely be gas, but no increment has been applied here for the steady price rise in gas over 50 years. Note that a 10GWe Wind system has a peak rating of 30GWe and is something of an elephant in any power supply mix. Other solutions to the problems of intermittency and power spiking will be developed to get the best out of wind power.

Finally, nuclear power turns out to be the cheapest and most reliable source of electricity over the next fifty years, including decommissioining and waste treatment. The stability and independence this would give could guarantee 10p/kWh electricity for 50 years.

We conclude that the best option for UK coal is to replace it entirely with Nuclear and Wind power. Gas would follow from about 2030. The same policy around the world may be able to avert the rise of global warming – a massive change if China and the USA are to eliminate the use of coal in this century.

## V. Collected Results & Comments.

The three comparisons presented above bring together the different economic and technical features of each power source. The cost of primary systems over a 50 year timescale is the final separator.

1. Solar PV and Wind based micro-power in the UK are not a competitors for large scale power generation. They are much more plausible in hot countries or where there is no national grid. There are niche applications for such micro-power in the UK. By contrast, the Energy Challenge report says:

   > 'we must grasp the opportunities offered by distributed energy today.'

2. Wind power is the most competitive renewable energy source but new transmission lines, grid controls, and intermittent industries or new energy storage mechanisms are needed to take full advantage of it. The Energy Challenge report commits to a continuance of the Renewables Energy subsidy which should be largely applied to Wind power and energy research.
3. Electricity from gas will definitely be the most expensive option over a 50 year timescale. It will have to be abandoned as a principal (>25%) energy source after 2030. The UK strategy of going for an 80% reliance on gas by by 2020 was never plausible as a way to provide secure, affordable energy in the UK. The Energy Challenge document recognises the problem of growing gas prices but states that replacement of existing nuclear stations could reduce gas consumption to 70% by 2020 and 65% by 2030. This is not nearly enough, and does not also replace the big polluter, 30 GWe of Coal.
4. Predictions of fuel prices are rapidly proving to be wrong and the efforts of the last decade by agencies everywhere to work out possible scenarios are unreliable, even on an annual basis. Energy policy needs to reflect this concern.

   The Energy Challenge report makes no actual predictions of gas prices but does call for more infrastructure, with the official belief that markets are the best mechanism to achieve all goals. It writes of the impact of a 1p/therm increase in gas prices but has nothing to say about the actual 40p/therm rise between 2003 and August 2006.
5. Carbon capture and storage, using the IPCC numbers, seems far too expensive for the UK, the best option being to phase out coal as soon as possible in favour of nuclear power. The long term goals to reduce emissions should not be compromised by approving new coal stations just in the hope that something will happen with CCS. Higher efficiency and lower emissions of other pollutants do contribute to cleaner coal, but this is not on the path of a 60% reduction of $CO_2$ by 2050.
6. The Energy Challenge report highlights recent efforts to secure oil company business in buying our $CO_2$ waste to recover more oil and thereby defray the initial cost of some CCS infrastructure. Since the EU as a whole may wish to pursue this more vigorously, we may do best to join the scheme when it is operational in 2020-2025.
7. Nuclear Power is already the cheapest electricity source in p/kWh or by long term costs and offers the greatest security of supply. The Energy Challenge report confirms that no subsidies will be forthcoming for nuclear. The nuclear industry has confirmed they do not seek any but do need firm commitments on licensing, regulation, and planning.

Other comments are:

- The EU Emissions Trading Scheme remains a suspect protocol for reducing emissions.
- Spent fuel and depleted Uranium will become an enormously valuable fuel resource by 2050, allowing our French operators to run the UK's advanced reactor fleet for hundreds of years, quite independently of other Uranium sources. This will overturn much of the fuel disposal plans of CoRWM.

- Generation III+ reactors are ready for final demonstrations to be built. Generation IV nuclear reactors, including Thorium based systems, should be ready for demonstration by 2030.
- The UK should make its contributions to a very strong EU programme of research into all new energy sources throughout this century..

The simple calculations shown have levelled the playing field for electricity cost comparisons. The differences between systems are very large and so another choice of well worked data sources, different from the RAE, IPCC, and others, will not alter the broad conclusions. There is much to be done and the global surge in new energy systems will be a considerable stimulant to the global economy. The technological solution to the problems of Climate Change, Fuel Change, and Poverty can be achieved if government policies can maintain a vision on the timescales over which solutions can contribute.

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