A way forward for nuclear power

by Adrian Ham and Robert Hall

Outline

A 2006 Energy Review Submission
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1.Executive summary

1.1. The announcement of a new energy review by the Prime Minister at the end of November 2005 followed two years of international energy and environmental shocks. But the stark reality of the international environmental crisis was well known to government ministers and Whitehall at least five years earlier. Energy specialists had been commenting on the instability of world oil prices and the rashness of over-dependence on natural gas for a decade. Yet there was no real energy policy in place despite the publication of an energy white paper in 2003.

1.2. That document could best be described as visionary but complacent. Very grandiose in terms of stated aspirations, very limited in terms of policy solutions. Indeed, the main relevant policy instrument, the Renewables Obligation, had already been introduced the year before.

1.3. It went for the bold aspiration of 20% renewable electricity in the UK by 2020. It blandly asserted that the liberalised markets for gas and electricity (a path breaking UK experiment) would provide virtually all the answers. It gave short shrift to fears of energy instability or shortage in the future. It set a clear and welcome target for carbon dioxide emissions - 60% CO_2 reductions by 2050. On energy security it stated: "Our goal is that people and businesses can rely on secure supplies of energy - gas, fuel and electricity - at predictable prices delivered through the market. Reliable energy supplies are an essential element of sustainable development… The energy supply risks that we face are important. But we believe they are manageable." (White paper, February 2003)

1.4. Two and a half years later, wholesale electricity prices were up by 170%, and wholesale gas prices were up by around 190%. Rarely can a government policy document have been so thoroughly and swiftly confounded by events. And CO_2 emissions had increased by two per cent since 1997- the increase from 2002 to 2004 was two and a half per cent (i).

1.5. Turbulence in the UK's energy markets did not come about because they failed as markets. Trading did not stop, and profits continued to be made. Competition was present and often intense. But subsequent price rises in gas, oil, and electricity have gone beyond the most extreme limits considered in 2002 and 2003. They have been and will be damaging and disruptive to industrial and domestic consumers alike. Forty per cent of our energy needs comes from gas, and within ten years most of that will be imported, with its price undoubtedly closely linked to the price of oil. In the vital field of electricity, the UK is approaching greater vulnerability to external supply disruption than at any time in the past four decades.

1.6. Since the UK became an oil exporter, successive governments have turned a complacent eye to the issue of energy security, especially that of electricity. Continuous electricity supply is critical in the modern world. We are not insulated from the concentration of market power in world gas and oil markets. Price movements historically have been very erratic. Furthermore government policies combine with the preference of international corporations to extract oil and gas reserves at maximum speed, for obvious economic and fiscal reasons. For a decade, there have been warnings on the vulnerability of placing too much reliance on future availability of gas from outside the UK. These came from the nuclear industry itself of course (ii), but also from sources as diverse as the *Financial Times* energy reports (iii), National Grid Transco (iv), the Institution of Civil Engineers (v), and reports from independents like Wood Mackenzie (vi), and the Adam Smith Institute (vii). Even the government's own background review documents in 2001 highlighted the danger.

1.7. One stabilising source of energy security over the past three decades in the UK has been nuclear power, which was contributing nearly a quarter of the UK's electricity in the early 1990s, not adding to global warming, and not subject to the vagaries of weather, coal shortages or world oil prices. Indeed our closest European neighbour, France, supplies around 80% of its own electricity needs from nuclear power, has provided about 3% of UK needs over the past twenty years, and has industrial electricity prices rather lower than the UK, even after fifteen years of the UK's experiment with a liberalised electricity market, and the UK's abundant supply of cheap gas.

1.8. The UK however, has accumulated a huge backlog of nuclear cleanup costs and problems. Why is this, and is it relevant to decision making today? The argument here is that these costs and problems are the result of the UK's peculiar history in nuclear experimentation, our desire to be a military nuclear force in the world, and an uncontrolled tendency to modify and alter designs and technology as we went along, rather than to replicate. In the French case, some fairly simple guidelines for nuclear choice were worked out at a crucial time by technical committees driven by politicians, which gave the French the chance to benefit from US designs, and replicate models on a big scale. This allowed them to get costs down whilst maintaining very high standards of safety, both in design and in operation, and minimise long-term waste problems.

1.9. A further key question to pose is - how is it that the privatised part of the UK nuclear industry had to come back to the government for assistance when the rest of the industry was in general making profits, and what could guarantee that this did not happen in the future? In this submission, it is argued that the market strategy itself was flawed, and that the delayed privatisation of part of the UK nuclear industry placed it at a crucial disadvantage compared with the major fossil generators.

1.10. Most of the UK generating industry is now in the hands of major foreign multinationals, quite contrary to the original policies of the earlier electricity regulators, who sought to fragment the industry to promote competition. The market as operated has simply pushed the nation rapidly into strategically damaging dependence on external sources of energy. Initial environmental benefits from replacing coal with natural gas generation are ended. But more may come; the rearguard action to subsidise wind power into a major position in the market has achieved little so far.

1.11. More recent developments in the electricity market have been environmentally perverse. The new market arrangements called NETA (New Electricity Trading Arrangements), introduced by the then Energy Minister Peter Hain, meant that more coal was burnt, at the expense of environmentally superior gas, renewables etc, because of technical aspects of the market rules. The very price instability the market has engendered means that, after the initial dash for gas, there has been reluctance to carry out substantial investment in generating of any kind, because the risks have become so great. Prices have fluctuated by increasing margins year to year, and the hedging of sales has not proved possible except over very short time periods.

1.12. None of this bodes well for future developments when the UK's own supplies of gas dwindle. Reliance on long term liquefied gas supplies from unstable Middle Eastern regimes is not a comforting solution. Nuclear power has in the past acted as a crucial support to energy security - unaffected by OPEC developments and run safely under well-respected regulators who understood the business and its technology. Nuclear deserves to be back on the agenda, but this cannot be on the basis of the shaky market framework that exists in the UK today.

1.13. The key questions posed by government in its review (viii) are:

2006 review key questions (abbreviated)	**Response developed in this document**
Q.1. What more could the government do…to ensure…..goal of reducing carbon emissions is met?	Q.1. The UK must learn from its past in nuclear policy . Nuclear could offer long-term reliable quantities of base load carbon free power. The unstable market presided over by government is not delivering price stability or carbon reductions. Long-term contracts must be available under new market arrangements to facilitate investment in adequate nuclear and renewable power.
Q.2 **..**What further steps…should the government take to develop our market framework for delivering reliable energy supplies?…	Q.2 Government must recognise that the market as currently structured will not deliver price stability or long term energy security. A facility guaranteeing longer-term contracts for carbon free electricity, extending the scope of the current Renewables Obligation is required.
Q.3. Are there considerations that should apply to nuclear.... as the government examines the issues .. including long-term liabilities and waste management?	Q.3. Government must appreciate that successive administrations have ducked the issues of nuclear waste - since 1976 or before. These are not significant technical problems, but political ones. There are now strong reasons to avoid further dilatory behaviour.
Q.4 Are there particular considerations that should apply to carbon abatement and other low-carbon technologies ?	Q4. Facilitate long-term (twenty year plus) contracts for purchasing carbon free power. Introduce a 'Carbon Free Obligation' tranche of electricity supply alongside the existing RO.
Q.5 What further steps should be taken…for ensuring...every home is adequately and affordably heated?	Q.5 This question is not discussed in this paper. But it is noted that France (with 80% electricity supplied from nuclear) supplies electricity to small domestic consumers more cheaply than does the UK.

1.14. This paper does not address all these challenges. It focuses on the first and fourth issues, which are relevant to the final challenge. The recommendations of this submission are for government to:

a. **Work to achieve a cross party consensus on the need for increasing percentages of carbon free power**
b. **Establish a consensus on the need for energy security guaranteed beyond market arrangements**
c. **Facilitate large extensions of obligations to supply carbon free electricity well beyond 2015**
d. **Evaluate properly and thoroughly market mechanisms which should be employed to strengthen the efficiency with which the above objectives are reached, and which would be compatible with trans-European energy markets**

2. Government decision-making

2.1. Nuclear activity in the UK has been promoted by both major political parties, during the past five decades (ix). Initially, because it provided a technological underpinning to a defence programme. Then, because nuclear power offered a strategic backup to coal generated electricity (Appendix A). And later, because it offered a strategic backup to oil generated electricity. It was not continuously promoted in the UK as a cheap option to all the alternatives.

2.2. Only when it appeared that domestic sources of oil and gas were abundant did governments of each major party feel relaxed enough to watch nuclear shift into decline. An initial adoption of the most naïve view of what markets could provide led to assertions about the automatic provision of diversity, and the automatic provision of low stable prices. A path towards monolithic reliance on the cheapest then known fuel - natural gas - was a natural consequence (Appendix B). Tinkering with market mechanisms up to the introduction of NETA made no difference to this trend, and the UK market experiment led to reliance on natural gas for electricity at a time when UK resources, quite predictably, began to run out. The introduction of the Renewables Obligation (RO) in 2001 was a recognition that the market could not be relied on to provide carbon free generation without intervention, but it did not go far enough.

2.3. It has been well recognised that government cannot escape involvement in strategic planning for power generation and particularly nuclear power, even in relatively liberalised market situations. Malcolm Grimston, Chatham House energy expert said: ‘So politicians simply must be prepared to take difficult and (in the short-term at least) potentially unpopular decisions to safeguard long-term prosperity, the well-being of the environment, social stability and so on’ (ix). And as the OECD put it: ‘Governments have a role in looking at the long term to compensate for the high discount rate and short term perspective of competitive markets, through appropriate tax incentives and other mechanisms’ (x).

2.4. Key events in the UK nuclear power programme (see Appendices A and B)

Decision-making chronology 1944-2006

1943	Churchill approves Quebec agreement
1945	Labour government continues nuclear programme
1947	Construction of first reactors at Sellafield commenced (Labour government)
1953	Construction of Calder Hall commenced (Conservative government)
1955	First government white paper "*A Programme of Nuclear Power*" (Conservative government)
1956	Calder Hall in operation and opened by HM Queen Construction of Berkeley and Bradwell commenced
1956/57	Suez Crisis – followed by the imposition of petrol and oil rationing
1957	White paper to increase scale of nuclear power programme (Conservative government) Windscale pile 1 accident
1962	Commissioning of Berkeley and Bradwell
1963	Commissioning of Windscale advanced gas-cooled reactor (WAGR)
1964	White paper on second nuclear power programme
1965	Choice of the advanced gas-cooled reactor (AGR) for Dungeness B and subsequent plants (Labour government) White paper on fuel policy expands second nuclear power programme (Labour government)
1965/66	Commissioning of Hunterston A, Hinkley A, Trawsfynydd, Dungeness A and Sizewell A
1967/71	Commissioning of Oldbury and Wylfa
1970	French abandon gas-graphite reactors and go for Westinghouse PWRs
1974	French commence series construction of identical 900MW PWRs at the rate of 6 or 7 per year, initially 16 in total, but eventually 34
1976/85	Commissioning of AGRs Hinkley B, Hunterston B, Hartlepool, Heysham, and Dungeness B
1974	Parliamentary select committee recommends that future nuclear plant should be steam generating heavy water reactors (SGHW). Labour cabinet supports SGHW
1976	Tony Benn, Energy Secretary, supports oxide reprocessing plan at Sellafield
1978	Third nuclear power programme, to comprise two more AGRs (not the SGHW), with the option later of a PWR (Labour government)
1980	Construction commenced of AGRs Heysham II and Torness (Conservative government)
1982	French Westinghouse contract expires, future plants are of 1,450MW capacity and of fully French design
1983/85	Sizewell B (PWR) public inquiry
1987	Construction of Sizewell B commenced (Conservative government)
1988/89	Commissioning of Heysham II and Torness
1989	Electricity Act (Conservative government)
1990	Privatisation of CEGB and Area Boards - creation of Nuclear Electric plc (Conservative government)
1994/95	Commissioning of Sizewell B (Conservative government)
1996	Privatisation of British Energy (Conservative government)
2002	Energy review - government rescue of British Energy (Labour government)
2005	Massive rise in electricity prices, gas prices, oil prices
2006	New energy review (Labour government)

Sources: UKEA, 1984 and Electricity Council, February 1982

3. The market experiment

3.1. A flawed programme of the liberalisation of the UK electricity market has not led to a lasting breakthrough in electricity costs to the consumer (Appendix C). The British public has lost its state assets, some holders of shares have become rich, many financial institutions have grown wealthy on the back of the process, and we have switched dependency on domestic coal as our primary fuel to a growing dependency on gas from overseas. The invasion of the free market space by giant trans-European companies diminishes state influence on the future of a major strategic industry. Where was the joined-up thinking?

3.2. Both the supporters of the old world (pre-privatisation) and the proponents of the new ignore some basic facts about human behaviour. All organisations – privately owned or state run - are subject to errors, and subject to slow deterioration if they are not driven to innovate and reform. Stimuli can either come from the outside, like the market or national emergencies, or from inside led by innovative individuals. At some point an outside stimulus can itself evolve into a crisis, which either reforms or destroys the inefficient organisation, or brings in a more durable substitute.

3.3. The market happens to be a very good instrument for provoking crisis, but not always for generating the ideal or even stable solution. In some commodities, the market is the best instrument for both purposes but in very heavy investment, high technology industries, an interaction with national interests and well considered national level intervention from outside the market is often a desirable development. Continual market turbulence can even become a blockage to beneficial reform.

3.4. Where external considerations like global climate change are concerned it is vital that government plays an active role. It is already accepted within the UK that for a country of our size to have a successful private sector high technology industry such as aerospace, special government instruments like Launch Investment (xi) are required.

3.5. At the global level, key energy variables like the price of oil have dominated economic development of the industrial world since 1945. But the presence of dominating global major companies (such as Exxon, Lukoil and Shell) as well as the intermittent success of OPEC and Saudi Arabia to affect world oil prices and production means that world oil prices are rarely far removed for politics: either the politics of OECD versus oil producers, or the politics of the major world oil giants. Market fundamentals, like the reality of oil reserve assessments, are hard to come by. As we have moved into a world where natural gas has become the fuel of choice for electricity generation, we find that the old tensions between national politics and the politics of the oil giants or their close neighbours still have a paramount role. Russia's interests will coincide with those of Lukoil and Gazprom, the Middle East will become a source of liquefied gas, technologically supported by the western world oil giants and whatever giant enterprise represents the fossil fuel interests of China and India.

3.6. Since energy is so far removed in significance and nature from the markets for corn, pins and clothes that so exercised the minds of the classical economists, we are obliged to look at policy in the future with rather more sophistication than the more ardent market enthusiasts. But at the same time, we can easily see why it was perceived in the UK that the institutions that had dominated the energy scene - the Department of Energy, the Coal Board, the CEGB and British Gas - had indeed in 1990 exceeded their sell-by date. Reform was in the air.

3.7. It should be noted, nonetheless, that the CEGB structure had delivered in various important regards over the previous three decades. Life for the old CEGB had not been without crisis, nor free from internal drives to change and improve. Crisis had arrived in the form of acute oil shortages in the 1970s, at a time when much new investment as elsewhere in the world had gone into oil burning generation. Crisis had also been acute in the early 1980s when the drawn out miners' strike challenged the ability of the CEGB to keep the lights on at all. Real prices of electricity to the consumer were indeed driven down steadily, and in 1990 UK electricity prices were not significantly different from those in other major European countries.

3.8. In the case of British Gas, the switch to natural gas burning and exploitation of the North Sea natural gas reserves had indeed been driven by the state owned giant.

3.9. A key recommendation in the Flowers report of 1976 (xii) was that the UK should not embark on an expansion of nuclear power unless the question of waste disposal had been resolved. This was an issue of public acceptability of solutions, therefore a political rather than a technical issue. Waste could be stored safely above ground– the issue was where should it go in the long term. Unfortunately, political preference to delay has been dominant - like the decision to abandon a four site study on long term low level waste storage before the 1987 general election. By 1990, when privatisation arrived, the CEGB could not easily assess the full cost of nuclear generation. The interpretation in Whitehall was that there had been a deliberate attempt to conceal the truth.

3.10. Fifteen years of UK attempts since 1990 to work out the long run costs of waste disposal have still not yielded great clarity. But the UK nuclear legacy of waste is highly complex. Our programme has been driven by diverse considerations ranging from a desire to keep up with the US on nuclear weapons to a desire to innovate in almost every possible new nuclear technology, and every new nuclear construction. The government created the Nuclear Decommissioning Authority in 2005, to establish priorities and a clear timetable for dealing with clean-up and decommissioning of the extensive civil fleets of retired or close to retired nuclear plant of all kinds. Thus at last government showed itself apparently willing to discover the full legacy and waste bill created in fifty years of experimentation and evolving technologies. Just as importantly, it appeared willing to get on with the job. But it faces a much more complex problem than that related to the French programme.

3.11. Countries like Sweden and Finland have successfully consulted the public, and found waste storage solutions at a pace that puts the UK to shame. It is true however, that they are unburdened by the problems of the heterogeneous legacy of waste as created in the UK, nor for the power produced the same volumes of waste. Our large scale magnox and AGR development has produced more than four times the volume of intermediate and low level waste as that which would have been produced by an equivalent output from PWRs (Appendix A, 11.3).

3.12. There is a wide belief that UK public administrators cannot resist perpetually reforming policy instruments. This view was held for many years in the context of economic policy, but now policy over electricity markets shows the same phenomenon with all its inevitable drawbacks. First, there was an electricity pool, where a half hour price was set for every half hour of the day all the year, and published. A new ‘improved’ system (NETA) was introduced by Energy Minister Peter Hain in early 2001, which was supposed to deal with market abuse. Under NETA, there was no longer a transparent market-clearing price, and all sales had to be contracted in advance of a specific trading series of deadlines. The idea was that this would avoid price manipulation, and prevent market abuse.

3.13. Although the early regulators (precursors to OFGEM) set out to break up large market players, the drift throughout the latter part of fifteen years of market experimentation was towards bigger vertically integrated generators, and to a greater and greater dependence on natural gas. Short-term considerations ruled, and in the short-term, gas was cheap. No consideration of national security was apparent in the respective regulators’ innovations or actions. The UK now depends on natural gas for 40% of its electricity generation, and 40% of its energy needs overall. This compares with a European Union average dependence on gas for 18% of its electricity generation, and 24% of overall energy consumption.

3.14. If the UK had been a major producer and exporter of gas into the very long term, like Norway or Russia, this would have been a reasonable policy outcome, ignoring environmental factors. But the UK was never going to be a long-term producer of gas. And there was no policy involved, unless to let the market take its course could be described as a policy. The market efficiently found the cheapest short-term way of producing electricity but not the best long-term solution for energy security.

3.15. In terms of environmental objectives, even feverish market modification yielded very little. Despite an aspiration of 10% renewables by 2010 and 20% aspired for by 2020, we begin 2006 with 4% of power coming from renewables (most of it old hydro) and a daunting task to achieve the ambitious targets set in 2002. To reach the 2010 target, we would need to install and commission the equivalent of the entire wind production of Germany in the next four years, and to add the equivalent of the whole of present European wind production by 2020. CO_2 emissions were higher in 2005 than they had been in 1997, partly as a result of the bias towards coal production under the NETA rules, and domestic energy consumption per household is increasing. From now on nuclear plant will be phasing out more rapidly.

3.16. The European scene is moving towards more competition, but not British style. The French, long-term suppliers of electricity to the UK market, have sold a tranche of shares in EDF, which owns the old London Electricity (amongst other UK electricity companies, Appendix B table B6). They are allowing a certain level of competition in supply to large customers. But there is no question yet of selling off regional franchises, or of creating a pool, or anything like NETA. The Germans have allowed the old regional franchises to be bought out by very large national players like EON, which now also has a large stake in the UK market.

4.Future nuclear economics

4.1. When power generation is decided by a monopoly, whether state owned or otherwise, its consideration of the economics of long term options depends upon three major factors - the capital cost of the generation plant, the long term running costs of plant excluding fuel, and the long run fuel costs. In a more informed world, we now also seek to take into account external costs - particularly the environmental cost of emissions. A vital aspect of the methodology is the discount factor applied to both capital costs, decommissioning costs and all other revenue and cost streams. In a state monopoly situation, the discount factor may be decided by the state itself. In a private monopoly situation, it will be reviewed possibly by an external regulator, as well as by the corporate management. In stable conditions, they will tend to use a rate that is higher than existing real interest rates available on gilt securities, but not massively higher, if they see the long run market conditions as highly dependable. In electricity supply this has always been the case in major OECD countries.

4.2. However, in an unstable market situation, management of competing utilities will always add risk factors to the discount factor. In non-energy markets - fast moving consumer goods for example - this could mean real discount factors of 15% plus. In energy markets, the convention has been to use factors ranging from 5% to 15% - depending upon risk factors taken into account.

4.3. In 1991, a United Nations conference (xiii) of world experts on energy considered prepared papers including International Atomic Energy Authority (IAEA) assessments that the generating costs from nuclear LWRs (light water reactors, ie conventional style reactors such as Sizewell B) would be around 40 mills*(2p) in 2000-2010, compared to the best coal technologies at over 50 mills(2.8p), and gas CCGTs at between 25 mills(1.4p) and 50 mills(2.8p), depending on fuel price. In other words, conventional nuclear including all its costs of decommissioning would be quite competitive with gas and coal generation in most parts of the world in the early part of the century commencing in 2000.

*(*1 mill = one thousandth of a dollar)*

4.4. The five reports recorded below show the following:

- Nuclear is competitive with offshore wind in most comparisons from 2010.
- Nuclear is competitive with high technology coal with carbon capture.
- With low gas prices, modern gas turbines are the cheapest form of generation. But wholesale gas prices have doubled since all these estimates were produced, from 23p/therm to over 50p/therm.
- Nuclear and wind technologies are very sensitive to discount rates used in calculating costs.
- More advanced nuclear technologies are not yet figuring in widely disseminated cost comparisons- comparisons are usually based on the well-known Sizewell B type of reactor.

4.5. A report to the DTI in 2003, from AEA Technology (xiv) suggested the following comparatives for generating costs as used in their modelling exercises for future UK generation costs (at 2000 prices, discount rate 10%).

Table 1: Comparative future UK generation costs

Technology	**Average lifetime cost in pence p/kWh**	**Notes**
Modern gas turbine	1.89	Gas price assumed 23p/therm in 2010
Modern coal (IGCC)*	3.6	
New nuclear	2.86	
Wind off shore	3.05	

*Integrated gasified combined cycle

Source: AEA Technology, 2003

4.6. A study of the economic factors affecting the future of nuclear power in the United States was commissioned by the US Department of Energy in 2003. This included comparative costs of generation internationally, and was published in 2004. It should be noted that this was a time when natural gas was relatively cheap in the US. The following table draws out comparative long-term costs, assessed at an economic return of 10%.

Table 2: World comparative generating costs for new products

Technology	**$ MW, 2003 prices**	**pence p/kWh***
Nuclear, Finland	42	2.6
Advanced gas turbine, average, OECD	38-65	2.4-4.1
Gas turbine advanced, USA	27	1.7
Modern coal, OECD**	42-74	2.6-4.6

*exchange rate $1.6/£ approx
**coal represents average for OECD, integrated gasified combined cycle, no carbon capture

Source: University of Chicago, 2004

4.7. One of the key conclusions of the study was: “If stringent greenhouse policies are implemented and advances in carbon capture and sequestrations prove less effective than hoped, coal-fired LCOE (costs) could rise as high as $91 per MWh and gas fired electricity’s LCOE (costs) could rise as high as $68 per MWh. These LCOEs would fully assure the competitiveness of nuclear energy” (xv).

4.8. In presenting an account of the government's energy ambitions to the Royal Academy of Engineering, Clare Durkin, one of the most senior government officials with energy responsibilities, presented the following cost figures (xvi) for relative generation costs in 2004.

Table 3: DTI : Relative generating costs, 2004 prices

Technology	Cost range pence p/kWh	Comment
Gas 2020	2.1-2.2	Represents costs prevailing for each technology for plant completed 2020 onwards
Gas + carbon capture 2020	3.0-3.2	
Coal + carbon capture 2020	4.5-4.9	
Nuclear 2020	2.7-3.0	
Onshore wind 2020	2.5-3.2	
Offshore wind 2020	3.0-4.6	

Source: Clare Durkin, DTI, 2004

4.9. A thorough analysis of comparative electricity generation costs in the UK was published by the Royal Academy of Engineering (xvii), including a more rigorous analysis of renewable costs, taking into account the costs of intermittency in wind generation, hitherto ignored in many wind power cost analyses.

Table 4: Comparative generation costs

Technology	Base-load	Without standby	With standby
Gas CCGT	2.2		
Nuclear fission	2.3		
Coal IGCC	3.2		
Onshore wind		3.7	5.4
Offshore wind		5.5	7.2
Wave and Marine		6.6	6.6

Costs expressed in p/kWh, discount factor 7.5%

Source: Royal Academy of Engineering, 2004

4.10. Further cost assessments were presented by the chief executive of British Energy to a meeting of financiers in 2005 (xviii), showing the following comparisons.

Table 5: Long run cost assessments of nuclear power

Discount rate	Cost in pence p/kWh	Source of estimate
5%	1.5	Finland
8%	2.4	Royal Academy of Engineering
10%	2 - 3	OECD Paris
13%	4	MIT, USA
15%	4	PIU UK

Source: British Energy, 2004. See BE website for presentation, 2006

4.11. Even if nuclear power in the UK was competitive against all other forms of power after 2010, if the market is perceived as being unstable and unreliable investors will not be interested in risking very large amounts of money. The unitary risk of nuclear is clearly a very significant factor, since the capital cost of one new reactor would be around one billion pounds for each thousand megawatts (MW) of capacity. Gas plant can be built in smaller units, as can coal. Offshore wind might face similar high unitary risks to nuclear because of the transmission network required to make a wind farm economic.

4.12. If government policy on generation and markets is seen as highly subject to radical change, no investor of scale will be willing to risk sums of money in the order of many hundreds of millions of pounds. By breaking up the CEGB we have ensured there is no UK enterprise with the scale and stability to take on such a risk, even with full access to world money markets, and even if the market for electricity had been totally steady. A national monopoly such as that in France, or even large regional monopolies as existed in the US and Germany facilitated this type of investment. With long run guaranteed off-take, on the other hand, nuclear investment can be feasible, as we have seen in Finland.

4.13. The UK market since 1990 as illustrated above has been subject to complex and frequent intervention, a high degree of volatility, and radical change. Indeed the UK government has made further long term investment in the generator field very unattractive, despite the RO, for renewables. The boom, bust boom cycle means that there is a lack of stability amongst generators and distributors, except those that have been bought out by major European players such as EDF and EON.

Furthermore, there is no certainty that the market in the UK at present will be anything like the UK market in another decade, after further integration with the European system.

4.14. Even at discount rates that would be high for a classic 'public good' investment, nuclear appears competitive with coal and gas for at least the next two decades if carbon capture is a required part of the evolving energy scene. A 60% carbon reduction target seems to make that virtually inevitable. We will almost certainly need very large additions of carbon free power. Therefore any extensions of carbon free contracts for electricity supply should not jeopardise the existing RO. It must be remembered that the implied scale of such a renewable installation is far larger than that existing anywhere else in Europe. This brings novel dangers as well as some possible benefits such as very long term returns to scale. The capital cost of such schemes is, however, daunting and subject to the same unitary cost problems as nuclear.

4.15. If we opt for a market system with the instability and frequent overhauls that seems to be the UK pattern since1990, there will be no potential investors willing to come forward, without matching purchase contractors of credible stature and willingness to undertake long-term off-take. Clearly in the Finnish case this situation was achievable, and in a partially liberalised scene such as that of France a partially liberalised generator has been able to make that decision.

5. Opening the door to carbon free generation

5.1. As has been frequently pointed out, electricity generation represents less than half the UK's consumption of primary energy, and less than half the UK's emissions of carbon. But radical changes in the other energy consuming sectors, such as transport, may well depend upon carbon free electricity as their basic feedstock.

5.2. A volatile and unstable market deters long term commitments. A combination of frequent market overhail and the inevitable strategic drivers of world energy prices have combined to create massive price turbulence, and may well do in the future. Yet long-term commitments are required for achieving long term goals of security and stability. Pure market liberalism is not enough. At the same time, it would be regrettable to retreat from the benefits of competition in energy. What will make long term investors put money into projects that may take ten years to yield positive cash flow? This must be the consideration of potential investors in either nuclear or new wind turbine fields deep offshore. In the latter case, there is comfort in the RO - but the financial rewards of the RO are as yet transitory and less than convincing. Even OFGEM investigating the functioning of the scheme in its first two years notes that the majority of respondents to its enquiry believe the 2010 renewables obligation will not be met. And although the government's target for 2020 is 20% renewables, the RO only extends up to 15% of supply in 2015.

5.3. The establishment of the renewables obligation instrument in 2002 sets the precedent for well-signalled and long term direction of an active electricity market towards greater energy security and greater reductions of carbon. Without interfering with the RO already established, it should be possible to state clearly and with cross party consensus a commitment to establish an extended carbon free obligation backed by long run competitive contracts to purchase an increasing tranche of carbon free electricity into the longer term. This could be open to new more efficient forms of renewable power not already established under the RO as well as to nuclear and modern coal with carbon capture. Mechanisms to achieve this could either be in the form of option contracts, or in the form of firm contracts backed up by a robustly constituted and legitimate form of state guarantee.

5.4. The RO offers a precedent and a sensible market tool that could be strengthened. The creation of a carbon free tranche of supply, building up to 20% by 2020, could allow competition between nuclear and carbon capture technologies ensuring a best cost tranche of supply after 2020. Innovation in carbon capture would be ensured if the price premium was seen to be adequate, and obligations could be introduced to contract well ahead. Or indeed government could support OFGEM in providing a long run contract cover for carbon free power, a form of hedging instrument for future suppliers of nuclear or other carbon free power.

5.5. Proposals put forward that could achieve very similar results are those of Dieter Helm and Cameron Hepburn (xix), Deloitte (xx) and Chris Hall (xxi), where a more subtle option approach is put forward.. An alternative to these proposals would be a straightforward carbon tax, which as the House of Commons Select Committee on Industry (xxii) has pointed out would also have the advantage of being directly subject to annual parliamentary approval and scrutiny, along with all the conventional tax instruments. However this might not achieve stability unless there was a cross party consensus on the urgency of the problem. A very useful round-up of the options is provided by the Deloittes' paper, and the Helm/Hepburn paper gives a very lucid and helpful commentary on the auctioning of long run carbon free supply contracts.

6. Recommendations

Government should :

a. Work to achieve a cross party consensus on the need for increasing percentages of carbon free power

If there is no solid cross party support, a question mark will be placed on market arrangements which favour future large scale investment in carbon free technologies, including nuclear. Thus conditions for investment confidence will be undermined, and financiers will demand unrealistic long-term returns.

b. Establish a consensus on the need for energy security guaranteed beyond market arrangements

It has to be accepted by government that in energy a free market does not assure stable prices and uninterrupted supplies, even if something like one could be obtained. Energy is traded internationally by very large organisations, bowing frequently to particular national exigencies and political strategies, and under no circumstance will they fit in with our chosen model of ideal markets.

c. Facilitate large extensions of obligations to supply carbon free electricity well beyond 2015

To meet the urgent requirement to cut carbon emissions by 20% each two decades or so, electricity supply offers the best proven technological remedies – particularly in the form of nuclear power. The French experience shows that large scale increases in nuclear capacity are feasible in a modern Western economy.

d. Evaluate properly and thoroughly market mechanisms that should be employed to strengthen the efficiency with which the above objectives are reached

Markets can be employed to ensure no ‘picking of winners’ and to reach objectives in the most economic way possible. There is no need for government to choose any individual supplier or even technology if large long-run contractual carbon free power is to be obtained within a competitive framework. It will be necessary, however, to ensure contracting parties are robust and capable of fulfilling their part of any supply deal. Such mechanisms must allow reliable contracts to be formed for long term carbon free supplies. Both large renewable projects and nuclear require long periods - in excess of 25 years - of guaranteed ‘off take’ to yield economic costs. Government should also seek to be better informed about energy developments. Its offshore relationship with OFGEM is insufficient to allow it to be aware of developments in the UK market or more widely. The surprise over British Energy for instance and the unexpected acceleration of dependency on imported gas suggest that the existence of the market excuses government from being up to date with developments.

ENDNOTES

(i) DEFRA press release, Jan 2006
(ii) 'Turning Point?', British Energy, 2002
(iii) 'The Future of Gas Exports from Russia', *Financial Times* Energy, 2000
(iv) John Wybrew, National Grid Transco presentation to British Management Data Foundation, May 2003
(v) 'The State of the Nation', Institution of Civil Engineers, 2003
(vi) 'From surplus to shortage?', Wood Mackenzie, 2004
(vii) 'International Contexts for UK Energy Policy', Chris Lambert, Adam Smith Institute, 2004
(viii) 'Our energy challenge', Government Review document 2006
(ix) Malcolm Grimston, 'The importance of politics in new nuclear build', Chatham House, 2005
(x) 'Government and nuclear energy', OECD, 2004
(xi) 'Launch Investment' is the phrase now used by DTI to describe government financial advances made to specific projects in the aerospace industry, like the airbus programme; A380, A320 etc. It dates back to before the Civil Aviation Act, 1982, and was one of the mainstays of continued UK presence in hi tech commercial aerospace.
xii) Sixth Report of the U.K. Royal Commission on the Environment 1976
(xiii) Senior expert symposium on electricity and the environment, key issues papers, International Atomic Energy Agency, 1991
(xiv) 'Options for a low carbon future - phase 2', AEA technology plc report for DTI, February 2003
(xv) 'The Economic Future of Nuclear Power', University of Chicago, 2004
(xvi) Clare Durkin, DTI, at Royal Society of Engineering, April 2004
(xvii) The Costs of Generating Electricity, PB Power Study, Royal Academy of Engineering, 2004
(xviii) British Energy website, 2006, Bill Coley presentation to Deutsche Bank, October 2005
(xix) Dieter Helm and Cameron Hepburn, Carbon contracts and energy policy: An outline proposal, 2005. See dieter@dhelm.co.uk
(xx) Deloitte Nuclear Discussion Series,2005. See www.deloitte.co.uk
(xxi) Chris Hall, Magnox Electric, 2006
(xxii) House of Commons Public Accounts Committee, Renewable Energy Sixth Report Session 2005-06, July 2005

APPENDIX A
A short history of nuclear power in the UK to 1990

1. Introduction

1.1. Our civil nuclear power programme grew out of the UK's post-war military imperative of producing plutonium for nuclear weapons. It did so in both the metaphorical sense of swords into ploughshares and in the context of the design and engineering of the plants. The UK had two plutonium producing reactors, known as the Windscale piles. These, together with their associated reprocessing plant, had been built in the remarkably short period of three years, work having started in September 1947 under a Labour government, and first coming into use in October 1950. The engineer in charge was Christopher Hinton, who was knighted for the achievement.

1.2. The design of the reactors comprised a large composite block of graphite (the "pile" of the name), through which ran horizontal cooling holes, into which were placed the uranium metal fuel, in the form of one inch diameter bars clad in aluminium cans. The whole reactor core was encased in a concrete "box", which provided the biological shield, and cooled by air blown through by powerful pumps. The heated air was discharged to waste through tall chimneys, capped with filters.

1.3. It was realised that changing the design could allow the heat to generate steam, and the steam used to drive a turbine to produce electricity. Hinton had proposed such arrangements for the first two reactors, but this had been prevented by the exigencies of time. The concept was however used at Calder Hall so the plants could produce both electricity and plutonium. Three important design changes were made from the Windscale piles. The most fundamental was pressurising the cooling gas (see also section 3.4 below) thus increasing the heat removal capability, and attaining much higher temperatures. This was important to increase thermal efficiency so that conventional steam turbines could be used. The pressurisation was achieved by surrounding the whole reactor core in a steel pressure vessel some two inches thick.

1.4. The second design change was a move away from using air as the coolant. This was necessary because a major component of air is nitrogen, and in compressed form this would be too great a neutron absorber for the reactor to operate with natural uranium, as was required because of the shortage of enriched uranium. The gas chosen was carbon dioxide, which is a reasonable heat-transfer medium, and which has a low neutron absorption. The third change was to use an alloy of magnesium as the cladding of the uranium bars, and to engineer into the cladding radial cooling fins, instead of the axial ones of the original design. It is this use of a magnesium alloy, MAGnesium-Non-Oxidisable, that led to the generic name of Magnox for the reactor type.

1.5. Work on the construction of Calder Hall began in August 1953, and the plant was opened by Queen Elizabeth in October 1956. It is worthy of note that this was a mere 14 years since the first man-made reactor was assembled in December 1942 by Enrico Fermi at the University of Chicago in the squash courts of Stagg Field – quite remarkable progress from a physics experiment to an operating power station. Again Hinton was the key to this success. The opening of Calder Hall was greeted with national acclaim – the Suez crisis was on, there was petrol and oil rationing, and the prospect of a new energy source was seen as a remarkable technical achievement. There was even a major spread in the *Eagle* comic giving a good quality explanation of the plant in the form of a sectioned drawing.

2. ***A programme of nuclear power*, government white paper, cmd. 9389, February 1955**

2.1. The government of the day recognised the importance of providing the nation with an additional source of power to fossil fuel, not least due to the extreme shortages of the latter. In February 1955 it published a white paper entitled *A* *programme of nuclear power*. The conclusion begins: “Our civilisation is based on power.” Later it states: “As a leading industrial nation our duty, both to ourselves and other countries, is to establish this new industry of nuclear energy on a firm foundation, and to develop it with all speed” (Ai). The primary strategic concern was to ensure a supply of energy, and nuclear power was, correctly, seen as a diverse source.

2.2. The strategic aspect is perhaps most graphically illustrated by the following quotation: “The provision of enough men for the mines is one of our most intractable problems, and is likely to remain so. In order to meet the present demand for coal recourse has been had to voluntary Saturday working as well as to opencast production and to imports; but the demand continues to increase. Any relief that can come from other sources of energy such as nuclear power will do no more than ease the problem of finding and maintaining an adequate labour force. There can be no question of its creating redundancy. The mining industry will in any case remain one of the major employing industries of the country, but it may hope to be relieved by the advent of nuclear power of the excessive strains which are being put upon it” (Ai).

2.3. The document was far-sighted about possible future technical developments, stating that the first reactors to be built would be based on the Calder Hall gas-cooled design, but that later plant would seek greater efficiency through developments to the gas-cooled system. Beyond that it discusses the probable development of liquid-cooled designs, which would permit a higher heat rating, and therefore be more economical to build. It also recognised the finite nature of the uranium resource and the need to develop fast-breeder reactors.

2.4. On costs, the document speaks of a “plutonium credit”, in that fissile plutonium can be extracted chemically from discharged irradiated fuel and can, in principle, be reused in newly manufactured fuel. Hence it should have a value. The paper explicitly excludes credit for non-civil use. (However, the commercial use of recycled plutonium in the form of so-called "mixed oxides” has only taken place comparatively recently.) The white paper suggests that with the plutonium credit, nuclear power can

generate electricity at about the same cost as a coal-fired power station, namely 0.6d per unit. In a separate paper it is indicated that without the credit the cost would be 0.9d per unit (equivalent to 6.5p per kilowatt-hour in 2004 money). The key objective of the document was to launch a strategically diverse source of energy, able to meet the anticipated increase in electricity demand without a proportionate need for increased coal production. Future developments would lead to competitive costing compared to fossil fuels.

2.5. The programme proposed was as follows:

- the construction of two twin-reactor power stations to start in mid-1957, to be in operation in 1960-61
- the construction of two further twin-reactor power stations (of the same basic design, but with improved performance) to start in 1958-59, to be in operation by 1963
- the construction of four more stations to start in 1960, and a further four in 1961-62 - these later stations were envisaged as being of a developed design, and possibly the later ones would be water-cooled.

This would give a generating capacity of between 1,400 and 1,800MW by 1965.

3. The route to realisation of the programme

3.1. Up to the date of the white paper, power stations had been constructed to the design of the Central Electricity Authority (CEA), which was the successor to the British Electricity Authority, with the components being supplied by industry and the construction controlled by the CEA. This practice was not to be continued for the nuclear power station. Instead there would be a series of turnkey projects, with the responsibility for design and construction in the hands of a number of industrial consortia. At this time the Central Electricity Generating Board (CEGB) was brought into existence with Sir Christopher Hinton its first chairman. He was appointed not least to assist in the implementation of the nuclear programme from the “users” side of the fence. At about this time he made a speech in Stockholm that included the following brief sentence, which aptly summarises the challenge of the civil utilisation of nuclear energy: “It is a feature of the design of atomic plants that the most daring progress must be made under conditions of the most stringent conservatism” (Aii).

3.2. Consortia were required because no one part of the existing industry had a capability for all the elements of the new power stations. Thus each consortium comprised companies competent in the fields of a heavy electrical engineering, boiler-making and civil engineering, plus bought-in skills in reactor physics and allied technical areas. It is probable that a significant element in the decision to follow the consortia route was the expectation of a considerable export trade in the new technology – at the time Britain was leading the world in planning a substantial programme of construction.

3.3. Four major consortia were put in place, to be joined by a fifth in due course. As the programme of new power stations was put in place, each consortium was “given” a contract for each new station, although there was some form of competitive tendering. The result was that each power station of the series was different in detail of design.

3.4. There were advantages in evolutionary improvements – for example the gas pressure at which Calder Hall could operate (and hence the heat removal capability of the coolant gas) was set by the thickness of the pressure vessel. At Calder Hall the maximum thickness that could be welded on site was two inches. As the series progressed, the capability for on-site welding developed, reaching a maximum (for Dungeness A) of four inches, and the electrical output per reactor was very substantially increased. Hence for a modest increase in capital cost, there was a disproportionate increase in electrical output.

3.5. However the lack of any concept of sister stations, or replication of design, meant that problems encountered at one site were not necessarily a useful indicator of concerns to come at a later station, and there was little opportunity for learning from mistakes. This would not have happened if a single organisation had been the “design authority” for the series.

4. Expansion of the nuclear programme

4.1. Recognising that measures needed to be taken to “keep the lights on” until the new plant was in operation, the intent had been to make up for the shortfall in coal production by the import of oil. The Suez crisis of 1956 led to the closure of the Suez canal, so that fuel had to take the long sea route from the oil-producing countries. This led to a severe shortage of oil by 1957, when petrol and oil rationing was imposed in the UK.

4.2. A white paper of April 1957, *Capital investment in the coal, gas and electricity industries*, proposed an increase in the nuclear power station construction programme to provide between 5,000 and 6,000MW of generating capacity by 1965. This was an increase of approximately a factor of three over the programme envisaged by the 1955 white paper, whose construction programme had only just commenced.

5. What was happening elsewhere?

5.1. **France** also wanted its own deterrent weapon, which required plutonium. Their initial programme was similar to the UK one, but (not least due to the consequences of slow recovery from World War Two) they began several years later. Construction of a series of three plutonium-producing reactors commenced in May 1954, the first (which was air-cooled, the remainder cooled by pressurised carbon dioxide) went into operation in January 1956. The later start enabled the French to incorporate a number of improvements, such as a limited recovery of waste heat from the cooling gas, which was used to generate electricity (Aiii).

5.2. In pursuit of the long-standing French energy policy, namely to provide France with the energy it needed at the best price, and to limit its dependence on other countries, a modest programme of construction of nuclear power stations was begun. Thus the French utility company, EDF, began construction in 1957 of their first civil nuclear power station, which had a generating capacity of 60 MW. It was of the gas-graphite type (the French name for what we called the Magnox reactors), and again was constrained in its design so that it could operate with natural uranium fuel. However, unlike the British models, instead of using a steel pressure vessel to enclose the core, they used a pre-stressed concrete pressure vessel. This had one outstanding advantage, namely that it gained its strength from the reinforcing tendons that could be individually removed for examination, enabling the safety of the structure to be readily demonstrated through the plant life. This feature was sufficiently attractive to be copied by the British in the last two Magnox power stations to be constructed, namely Oldbury and Wylfa.

5.3. **In America** the context was quite different. There was no immediate shortage of energy. Because of the large programme of plutonium production and relatively plentiful availability of enriched uranium for nuclear weapons, the designers of nuclear reactors could afford to use features that required the fuel to be enriched. What turned out to be the most significant development of all began with the decision to construct a nuclear propulsion plant for a submarine. This would confer on the submarine the almost magical capability of unlimited underwater endurance. The person in charge was the formidable Admiral Hyman G Rickover. He took the decision to use enriched uranium as the fuel, and pressurised water as the coolant and efficient moderator: "Because we know how to build pumps and pipes and valves to handle that"(Aiv). A key objective was compactness so that the plant would fit in a submarine. The high heat removal capability of pressurised water would enable a relatively high power core to meet this objective.

5.4. America had some experience of water-cooling in one of the reactor types they used for their plutonium producing reactors. This option was not available to the British or French, as there were aspects of that specific design which made it inappropriate to contract it in populated areas. The Americans had a suitable desert available for its siting. Construction of the land-based prototype of the submarine reactor began in 1949, and it was put into operation in March 1953. The first use of the pressurised water reactor (PWR) at sea was in the submarine USS Nautilus, launched in January 1954 (the keel-laying also earning a major spread in the *Eagle*), and which famously travelled under the polar ice to the North Pole in 1958.

5.5. Turning to civil applications, in 1954 the US congress approved the construction of a series of five prototype commercial plants, of very diverse designs. The most significant of these turned out to be the Shippingport PWR power station, which had 60MW generating capacity. Although constructed by Westinghouse, the reactor design was by Rickover's naval reactor team, a matter that aroused some concern from US industry at the time. It was commissioned in 1957 and has a good claim to be the world's first truly civil use of nuclear power for the generation of electricity on a commercial scale, noting that Calder Hall in the UK, commissioned in 1956, was a dual-purpose plant, also producing plutonium for military use.

5.6. **The Russians** were in a similar position to the Americans, namely with no immediate shortage of energy, and with enriched uranium available for use in experimental reactors for civil nuclear power stations. In 1954, their prototype APS1 at Obninsk, came on line, producing 5MW of generating capacity. It was fuelled by enriched uranium, cooled by boiling water in tubes that surrounded the fuel, with a graphite moderator. It was to evolve into the RBMK series. The Russians argue that this was the world's first civil power station, and it was certainly publicised as such at the 1955 “Atoms for Peace” international conference. Somewhat later the Russians built a series of prototypes of diverse designs, but the final designs chosen for further development were the RBMK, and the Russian PWR, known as the VVER type. This latter had originally been developed for use in nuclear submarines and icebreakers.

6. The Windscale accident and its organisational consequences, including the bringing into existence of the Nuclear Installations Inspectorate

6.1. In October 1957 what should have been a routine operation in Windscale pile 1 developed into a major problem. Because the reactors operated at relatively low temperatures, it was necessary from time to time to raise the temperature above the normal level, to anneal out radiation damage that had accumulated in the graphite. If this were not done, the stored energy would eventually be released in the form of potentially uncontrolled heating. On this occasion the annealing process did not proceed normally and the reactor overheated, eventually to such an extent that it caught fire. This resulted in the release of volatile radio-iodine from the tall chimneys up which the exhaust air passed. Filters installed at the top prevented a major release of other fission products. The fire was eventually put out by pouring water into the reactor. As a result of the release of radio-iodine, a temporary ban was placed on the sale of milk produced over a 200 square mile region, to close-off a potential path by which iodine could reach the thyroids of infant children.

6.2. There was a series of investigations, starting with a technical one aimed at understanding just what had gone wrong. One consequence was the precautionary immediate shut-down of pile 2, which was in fact never restarted. More significantly for the future, other investigations, chaired by Sir Alexander (later Lord) Fleck, chairman of ICI, examined the organisational aspects. The first result was to put into place, within the Atomic Energy Authority, an Authority Health and Safety Branch (AHSB), to separate safety supervision from plant operation.

6.3. Recommendations from the Fleck investigations also led most importantly to the Nuclear Installations Act of July 1959. This required that the civil nuclear power stations which were under construction and those planned for the future, which were to be operated by the CEGB, would be licensed by the newly formed Nuclear Installations Inspectorate (NII). Thus the UK civil nuclear power programme was to have in place a powerful regulator, whose only job is safety. At the time, Hinton recommended that the NII should also have oversight of the nuclear plant operated by the UKAEA. This advice was not accepted, but some three decades later the role of the NII was extended to include supervision of the AEA. The NII evolved into a technically thoroughly competent organisation, which has served the UK well.

6.4. The requirement to have such a separate, technically competent and powerful regulator has been recognised for many years in western countries. It is seen as a prerequisite for a safe nuclear industry. Its world-wide implementation has now been achieved through the activities of such bodies as the IAEA.

6.5. Throughout all this, the UK nuclear power station construction programme proceeded without a pause. There were good technical reasons why the Windscale accident could not take place in a pressurised carbon dioxide reactor. For example, because they operated at much higher temperatures than the Windscale piles, it was unnecessary to carry out overheating to anneal out radiation damage. However, a most careful graphite monitoring programme was put into place which continues to this day. It is surprising in retrospect that there were not vociferous calls for the construction programme to be halted whilst the matter was debated publicly.

7. The Magnox construction programme

7.1 The table below sets out the actual construction programme achieved for the Magnox power stations against the three tranches envisioned in the 1955 white paper. Thus the first line of each tranche gives the number of stations and their intended contract and completion dates, as set out in the white paper, and summarised in section 2.5 of this appendix.

Table A1: The Magnox programme

Tranche	Station	Contract date	Commission Year	Output MW
1	*2 intended*	1957	1960/61	
	Berkeley	1956	1961	270
	Bradwell	1956	1962	300
2	*2 intended*	1958/59	1963	
	Hunterston A	1956	1964	320
	Hinkley A	1957	1965	500
3	*4 intended*	1960	1963/64	
	Trawsfynydd	1960	1965	500
	Dungeness A	1960	1966	550
	Sizewell A	1961	1966	580
	Oldbury	1962	1967	600
	Wylfa	1964	1971	1180
3a	*4 intended*	1961/62	1965	
	none built			
Total capacity				**4800**

Source: CEGB

7.2. It can be seen from the above table that the overall capacity set out in the 1957 expansion of the 1955 programme was effectively achieved with fewer power stations than originally envisaged, due to the larger than anticipated scale-up of the size of individual plants. The programme was somewhat behind in time-scale, as originally completion had been intended by 1965. By that date a capacity of 2,126M was in place.

7.3. There were two reasons for this. The first, that problems were inevitably encountered in pushing forward a new technology on an industrial scale, with each consortium having to learn its own lessons as the plants were being constructed in parallel. The second reason was that in June1960 the government put back the date for the achievement of the 5,000MW target to 1968. This was because oil prices, which had been at their peak in1957, had fallen considerably, so the shortfall of availability of coal was being made up by burning imported oil in newly constructed oil-fired plants. This "benefit" was to prove a hostage to fortune some years later with the various oil crises. It has been noted since that "It took five years to build a Magnox plant; national fuel policy was re-appraised, on average, once every three years during the 1960s" (Aii).

7.4. On a technical matter, from Calder Hall to Sizewell A, all the plants had large steel pressure vessels enclosing the reactor core. The last two plants constructed, Oldbury and Wylfa, had pre-stressed concrete pressure vessels, a concept borrowed from the French, and discussed briefly in section 5.2 of this appendix. It was believed at the time that this was the way forward for Magnox power stations, although in fact no more were built. The concept was, however, fully utilised in the AGR plant (section 8.10 of this appendix).

7.5. It is interesting to note that cheap power was not at the time considered to be the objective of the Magnox stations. The Duke of Edinburgh, on opening Berkeley and Bradwell stations in 1962 said: "The importance of these nuclear power stations far outweighs the immediate cost of the power they produce. The very steep rise in demand for electricity brought about largely by this weather, the practical limits on the use of coal above a set amount, the practical and economic disadvantages of relying too heavily on oil fuel – all these make it quite plain that nuclear power is going to play an increasingly important part in the British energy programme of the future" (verbatim from a BBC Radio Four programme "Return of the Atom" broadcast on 20/09/05).

8. The second nuclear power programme

8.1. There was concern that the overall thermal efficiency of Magnox reactors was significantly limited. This was because of their relatively modest steam temperatures. Steam conditions were poor in comparison with contemporary coal-fired power stations, and the manufacturers had found it necessary to use steam turbine techniques of some three decades earlier to best utilise the saturated steam.

8.2. Hence there was an incentive to change reactor type for any future expansion of the UK's nuclear power programme. The position in the UK at this time was nearer to that in the USA described in section 5.3 above. Enriched uranium was now in sufficient supply for military purposes, so some could be made available to the civil programme. The significance of this was that it enabled a much wider range of reactor designs to be considered, once the constraint was removed of using only natural uranium.

8.3. This point is illuminated by the remarkably diverse activities of the UKAEA in the 1960s. It was progressing the design of a liquid-metal cooled fast reactor, which was being constructed at Dounreay – once more to the acclaim of a spread in the *Eagle*. At Winfrith it had a joint European project in the so-called "Dragon" reactor. This was a non-electricity producing experimental high temperature reactor using helium as a coolant. The objective was to be able to drive a gas turbine directly. It also had under construction at Winfrith a prototype power station of 100MW, of the steam generating heavy water reactor (SGHWR). This was commissioned in 1968, and used heavy water as the moderator. The fuel was cooled by boiling water in pressure tubes, the steam then being used directly to drive a steam turbine. In addition, and most significantly for the next part of the story, at Windscale there was under construction the Windscale advanced gas-cooled reactor (WAGR), which was commissioned in 1963 and had an electrical output of 30MW.

8.4. The WAGR was proposed following a review of the limitations of the Magnox reactor type, where the quest for higher thermal efficiency and the use of modern turbines was hampered by low gas outlet temperatures, necessitated by the metallic fuel. This had a relatively low melting point, as did the Magnox cladding. It was therefore necessary to go to a "ceramic" fuel that would stand much higher temperatures. Uranium dioxide was suitable. The fuel cladding eventually chosen was stainless steel, after flirtations with more exotic metals. The fuel design had to be quite different from the conceptually simple uranium metal bar of the Magnox reactors, due to the poorer thermal conductivity of uranium dioxide. The design chosen for WAGR was a cluster of thin fuel rods (initially 21, finally nine) held together by metal clips. The coolant was still carbon dioxide, but at a significantly elevated temperature and pressure as compared with the Magnox plant.

8.5. The result of the changes shows most significantly in the reduction in the volume of the WAGR core (70 cubic metres) as compared with that of Calder Hall (400 cubic metres), both having broadly comparable electrical output. These volume changes also had implications for long-term decommissioning costs.

8.6. It was noted at the time that the claim for family kinship between the Magnox reactors and those designs likely to evolve from the WAGR was unconvincing, and that the ability to use enriched uranium fuel gave the opportunity to review world developments before progressing. As we shall see in section 9.1**,** this is exactly what the French did.

8.7. In April 1964 the government published a white paper outlining a second nuclear power programme. New stations were proposed for England and Wales, to be in operation between 1970 and 1975, with a total capacity of 5,000MW. There was some flexibility in the plan: it was assumed this new programme would amount to four more stations, with the possibility of an additional one in Scotland if required by electricity demand. Most significantly, and in contrast to the first programme that was understood to have an experimental element, it made the assumption that the new plant would be economically competitive with fossil-fired plant by the commissioning dates. The CEGB was required to issue an enquiry for tenders for an advanced gas-cooled reactor station, but they were also "to consider tenders from British industry for water-moderated reactor systems of proved design, provided that full supporting evidence is submitted with the tenders, and the requirements of safety and performance comparable with those of the AGR are met" (Aii). Note the uncomfortable assumption that the AGR was a proven system.

8.8. At this time there were three consortia in existence, and they put forward tenders for a total of seven designs, being the three required AGRs plus a selection of water reactor designs. This process was wasteful of design resources, and did not necessarily enable an adequate effort to be put into any one design. The chosen site was next to the existing Dungeness A station, the new plant to be known as Dungeness B.

8.9. A year later, on 25th May 1965, Minister of Power Fred Lee announced the choice of a twin reactor AGR station of 1,200MW capacity, describing it as "the greatest breakthrough of all times" (Aii). The extrapolation from the WAGR prototype was remarkable. A new design of fuel, by definition untested, was proposed, with 36 pins – several times the number of the WAGR. This had the major economic advantage of reducing the number of penetrations required in the reactor vessel for refuelling. On-load refuelling was claimed to give an economic advantage over the water-cooled reactors. History shows it to have been an unrealised objective at Dungeness B. Overall each new reactor had an electrical capacity of 600MW, as against that of the WAGR of 30MW, a twenty-fold increase as compared with the Calder Hall to Berkeley ratio of a factor of two per reactor. The objective of using current turbine design had been met, but oddly Dungeness B was to be the lead plant for the new and untried 660MW sets. It is hard to accept now that the choice of the AGR was truly objective, and a strong element of "Buy British" at all costs would appear to have been involved – and the costs for Dungeness B proved to be particularly high.

8.10. The choice of an AGR for Dungeness B set the trend for the next four plants, which were all to be AGRs. They used pre-stressed concrete pressure vessels surrounding all the components of the primary circuit, including the boilers. This system had very real safety benefits but the expensive downside was that access for both construction and maintenance was severely restricted, since all the major components were housed inside the pressure vessel. The progress of the AGR construction programme is reviewed in section 10 .

9 Developments elsewhere

9.1. **France** constructed a limited series of gas-graphite (i.e. Magnox) reactors at Chinon, St Laurent and Bugey, the last orders being placed in 1966. The later plants incorporated various developments aimed at making the plants economically competitive, for example the use of higher gas pressures and an improved design of fuel element. The last of these plants (Bugey 1) was commissioned in 1972. To restate the French energy policy, namely “to provide France with the energy it needed at the best price, and to limit its dependence on other countries”, the objective now became to ensure that the nuclear programme (which conferred the required independence) was also economic. Bugey 1 had this intent, but failed. The French gas-graphite plants produced electricity at a higher cost than both conventional oil-fired power plants and enriched-uranium light water reactors. Concerns about potential problems with new designs ruled out possible contenders such as the British AGR, and the Canadian heavy water reactors (a cousin of the SGHW developed by the AEA). High temperature gas-cooled reactors were not ready for commercial exploitation.

9.2. Quoting from an EDF document “Common sense dictated the final decision: a first call for bids saw the triumph of PWR reactors built by Framatome under licence to Westinghouse. Fessenheim, then Bugey, were commissioned beginning in 1970 at a rate of one or two 900 MW units per year” (Aiii). This use of the PWRs was made possible by the success of the French programme for producing enriched uranium, which was available in sufficient quantities to satisfy both the military and the civil requirements. They had also gained technical familiarity with the PWR system by constructing one jointly with the Belgians at Tihange.

9.3. Marcel Boiteux, EDF chairman at the time, explains that the key decision on the scale of expansion of the programme was taken one Saturday morning in December 1973. EDF was planning to have under construction in 1974 two PWR power stations, with a definite capability of adding a third. Boiteaux was asked by the French minister of energy at 9am to report back to him by noon on the maximum possible number of new nuclear power stations which could be commenced each year "starting now". He states "It is always on a Saturday morning, in great haste, when great decisions are made." The answer given by EDF was "not more than six or seven stations per year" – and that was the number used in the French governmental decision (Av).

9.4. The intention to proceed with a "series" contract was announced in March 1974, as a result of which Framatome was awarded contracts for sixteen identical 900MW power plants. They eventually built a total of thirty-four. The programme continued with the launch of a 20 unit series of 1,300MW plants. The Westinghouse agreement ended in 1982, and the next series of plants was with a fully French design of 1,450MW capacity, the first being sited at Chooz.

9.5. The remarkable success of the French programme is explained by EDF as follows:- "The most important factor was the establishment of a clearly defined energy policy, consistently pursued by successive governments and supported by a civil service conscious of its responsibilities, inflexible with respect to safety, strict in its protection of the environment, but intent upon reaching the goal and efficient in administrative procedures" (Aiii). Contrast this with the scene in 1960s Britain quoted in section 7.3, namely "It took five years to build a Magnox plant; national fuel policy was re-appraised, on average, once every three years." The French energy policy continues to this day, with recent confirmation of the site for the first of the next series of reactors, based on an "international" design, the European pressurised water reactor.

9.6. A final quote from EDF: “It is a question of not being taken in by illusions in an area where illusions are all the more expensive because of the long lead time – ten years at least – between the decision to develop a new energy source and the start of actual production” (Aiii).

9.7. In America the initial sweep of orders for water reactors was largely an export one, with major interest from American electrical utilities not appearing until 1963. This latter included an interesting attempt by the Atomic Energy Commission (AEC) to interest small utilities and municipal authorities in nuclear power station with a small output. They did this by financing, and owning, the nuclear part of the plants. More successfully, the AEC also subsidised large power plant, typically providing and owning a 20% stake. The oil crisis of 1973 gave impetus to the construction of nuclear plants, which was ended by President Carter’s confused energy policies of the late 1970s. This included a total ban on the separation of plutonium. A further setback was the Three Mile Island accident of 1979; although the radiological consequences were negligible, the same was not true for financial, administrative and psychological consequences. Nevertheless by 1984 America’s nuclear generation was 13.5%, as compared with France’s 59% and Britain’s 17%o – and the scale of electricity demand in the USA meant that their actual nuclear generation capacity was much the largest.

9.8. In Russia, the end of the 1960s saw the appearance of standardised plant series, with outputs of 440MW, 1,000MW and 1,500MW. The designs of both the RBMK reactors (graphite moderated with boiling water flowing through pressure tubes containing the enriched uranium fuel) and the VVER (PWR type) were developed to meet these target outputs, and a substantial construction programme followed. This naturally included exports to the satellite eastern European countries.

9.9. Of course developments in the generation of electricity by nuclear power were not confined to the UK, France, America and Russia. These countries have been concentrated on because either they led the way, or were commercially dominant (or both) in their influence on the rest of Europe and the rest of the world. Within Western Europe, the proportion of electricity generated in 1984 by nuclear power was: Belgium 51%, Switzerland 37%, and Germany (Western) 23%. In Eastern

Europe: Bulgaria 29%, Germany (Eastern) 23%, and Hungary 14%. In the Far East:: Japan 23%, Korea 22% and Taiwan 48%.

10. Expansion of the second UK nuclear power programme and further developments

10.1. In the autumn of 1965, with the completion of the Magnox power stations somewhat behind schedule and power cuts once again being experienced, the government produced a white paper on fuel policy. This included an expansion of the second UK nuclear power programme to 8,000MW, implicitly accepting the commercial claims for the AGR, of which however the first had only just commenced construction.

10.2. The white paper also considered the supply of oil that had risen from accounting for 17% of Britain's energy in 1956 to 33% in 1964. No concern was expressed about oil reserves, and the drop in oil prices was taken as an indication that there was a glut that would guarantee supplies indefinitely. Concomitantly, there was to be a substantial run-down in coal production. There were those who (correctly) anticipated a future shortage of fossil fuels - a contemporary critic stated "You do not expect a government department responsible for one of the key sectors of the national economy to be blinkered or naïve, the Ministry of Power appears to have been both" (Aii).

10.3. There were many problems with progress on Dungeness B, the causes including errors in design, mistakes in the fabrication of components, and faults in construction on the site. Eventually, in1969, the consortium involved was effectively declared bankrupt, and subsequently existed on paper only. The CEGB set up a management agency to run the construction project. It was to be nearly 20 years from the start of construction before the plant generated electricity, and still more before it did so reliably. Its eventual production of reliable power is a tribute to the skills and remarkable dedication of the engineering and operational staff involved.

10.4. The construction programme for the series of advanced gas-cooled reactor power stations is shown in the following table.

Table A2: The first AGR programme

Station	Contract Year	Commission Year	Output MW
Dungeness B	1965	1983-85	1200
Hinkley Point B	1966	1976	1250
Hunterston B	1967	1976	1250
Hartlepool	1967	1983-84	1250
Heysham	1970	1983-84	1250

Source:CEGB,

For the first time in the history of the UK nuclear power programme there was some replication of plant, in that Hinkley Point B and Hunterston B were sister stations, as were Hartlepool and Heysham.

10.5. Problems in the construction of the AGRs were not restricted to Dungeness B, although no others had such severe difficulties. All were several years behind schedule. Some problems, such as with the aerodynamic design of the fuel, were a consequence of the economically attractive choice of a larger fuel bundle than that which had been fully tested in the WAGR prototype. But perhaps the most fundamental difficulty with all the AGRs was that a great deal of the high technology construction and assembly had to be done on site, and in-situ inside the pre-stressed concrete pressure vessel.

10.6. Looking ahead to future plant, the CEGB was expressing interest in the American design of PWR. Because of its high power density and hence small physical size (by comparison with the AGR) most of the challenging high-precision construction work could be carried out in the factory, and the components then transported to site for assembly. Looking further ahead still when the success of the French "peas in a pod" series construction programme became manifest, the CEGB had a clear goal – which was not to be fully attained.

10.7. However as late as 1972 the CEGB had plans to build a high temperature reactor (sometimes described as the Mark 3 gas-cooled reactor to follow the Mark 2 of the AGR and the Mark 1 of Magnox) at Oldbury B; similarly but differently, the SSEB had plans to build an SGHW at Stake Ness. Both were cancelled due to lack of government support.

11. Towards a third nuclear power programme

11.1. In 1973 the CEGB, under its chairman Arthur Hawkins, announced that future planning should consider only proven systems, and in the autumn of that year published a programme of 18 large nuclear power stations, each of 2,400MW capacity, to be ordered between 1974 and 1983. The earlier plants were to be twin PWRs with the possibility of the later plants being of more advanced design. Similarly but differently, SSEB, under its chairman Francis Tombs, proposed a programme of 8 SGHW plants. This was the preferred plant of Lord Hinton, as he became following his retirement as chairman of the CEGB in 1964. The large scale of the overall programme can perhaps be explained by the fact that electricity demand had grown by a factor of three between 1955 and 1975, and that trend was expected to continue.

11.2. The matter was reviewed by the Parliamentary Select Committee on Science and Technology, which reported in early 1974. In the words of its chairman Arthur Palmer MP, speaking at an industry meeting at the time, “If eminent engineers cannot agree, then the politician has to decide”. The outcome was an announcement in June 1974 that the UK’s third nuclear power programme would consist of a series of only six reactors, each of 660MW capacity, and the reactor type would be the SGHW (steam generating heavy water reactor) of which a 100MW prototype was operating at Winfrith - back to “Buy British” again.

11.3. However there was more to producing a commercial scale SGHW than simply scaling up from the successful prototype. Over the period 1975-76 the number of major changes required led to a meeting between the key players in the nuclear

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industry (including Arthur Hawkins and Francis Tombs) and the Secretary of State for Energy, Tony Benn. The intent was to continue with the SGHW. At about this time both the AGR stations at Hinkley B and Hunterston B commenced operation, relieving the bleak scene in which none of them had ever operated. Also the very thorough review of the safety of the PWR pressure vessel carried out by Department of Energy chief scientist Walter Marshall reported favourably. Thus there was a softening of the feeling against both the AGRs and the PWR. Arthur Hawkins then suggested in October 1976 the cancellation of the SGHW. All this only two years after the energy-shortage-driven three day week, when nuclear power was seen as the salvation. Now there was publicly visible confusion. Tony Benn records the events of early June 1976 in his diaries: 'I personally don't want the SGWR but I shall fight like a tiger against the American light water reactor'….'I think they all reckon on my going quickly and then they'll get the American reactor. But I'll be absolutely opposed to that and I might have some influence over the decision wherever I am in Whitehall' (Aix). Thus the Secretary of State for Energy took a personal stand against his civil service advisers on the light water reactor, PWR, which was to be such a success in France.

11.4. Publicly, the position remained unclear for more than a year until a statement was made in January 1978, which was in effect a restatement of the third nuclear power programme. Tony Benn announced that construction of two further AGR stations would be approved, and that the option of adopting the PWR system in the early 80s should be developed. Work on the SGHW would stop. The choice of the AGR for immediate construction can be seen as an "easy" decision for the politicians. The increasingly vociferous anti-nuclear movement was at that time focussed on the supposed dangers of the American PWR, whilst the AGRs were tacitly accepted, thus leaving the decision on a UK PWR as one to be taken in future was politically attractive._

11.5. The two AGR stations became Heysham II and Torness, each having two reactors, and work commenced on both during 1980. They were sister stations, and the construction programme went more smoothly than for the earlier AGRs. They were formally opened in Spring1989. The PWR plant was to be based on a

1,120MW Westinghouse design, the prototype being at Callaway, put into operation in 1984, and would be built, if at all. at Sizewell, as the B station. Work had commenced here some time before on the foundations for the SGHW.

11.6. A public enquiry was held to review the PWR's acceptability. The Sizewell B Public Inquiry became the longest-running Inquiry in Britain's history, commencing in June 1983, and closing in March 1985. Its report was favourable, and in due course work started at Sizewell B in 1987. Again , construction went smoothly, and the plant first generated electricity on February 14th 1995. The CEGB arguments for Sizewell B (Ax) were partly on economics, partly that it would reduce dependency on coal, and partly that it would ' .ease the problems of air pollution.'

Table A3: The third nuclear power programme

Station	Contract Year	Commission year	Output MW
Heysham II (AGR)	1980	1988-89	1240
Torness (AGR)	1980	1988-90	1240
Sizewell B (PWR)	1983	1994-95	1180

Source: CEGB, SSEB

ENDNOTES

(Ai) 'A Programme of Nuclear Power', CMD.9389, HMSO, February 1955
(Aii) 'Nuclear Power – Its Development in the United Kingdom', Pocock, R F, Institution of Nuclear Engineers, 1977
(Aiii) 'The Nuclear Age', Leclercq, Jaques Sodel, 1986 (sponsored by Electricitē de France)
(Aiv) 'The Rickover Effect', Rockwell, Theodore, Naval Institute Press, 1992
(Av) 'Haute Tension', Boiteaux, Marcel, Editions Odile Jacob, Octobre 1993
(Avi) 'The CEGB Story', Cochrane, R, CEGB, March 1990
(Avii) 'Britain's Atomic Factories', Jay, K E, HMSO, 1954
(Aviii) *Eagle* **:** Calder Hall, 21/12/56; Nuclear Submarine, 23/05/52; The Dounreay Fast Reactor, 18/10/57
(Aix) Tony Benn 'Against The Tide' Diaries 1973-76- Arrow Books 19990
(Ax) 'Power Tomorrow- Sizewell B -the Central Electricity Board's case', Geoffrey Greenhlagh, ISBN 1-85091-173-8

see also:
'The Development of Atomic Energy 1939-1984 – Chronology of Events', UKAEA, August 1984
'Electricity Supply in the United Kingdom - a Chronology', Electricity Council, February 1982

APPENDIX B

Chronology of the electricity market, 1990- 2006

1.Introduction

1.1. The purpose of this section is to set out the turbulent period leading from 1990 up to 2005, when nuclear fortunes in the UK 'rose like a rocket, fell like a stick', then began to emerge once more from the ashes. Some of these dramatic events were self-created; some were almost entirely the result of outside developments. None of the changes in fortune, however, could be said to relate to growing national and international concern over far more significant strategic influences, particularly climate change, for which nuclear almost certainly has very major role.

1.2. In Appendix A, we have seen how key personalities such as Lord Hinton had a major impact on developments for a whole industry. In the period now under discussion, several other major personalities feature. In developing the political and philosophical rationale for privatising the industry, we can easily identify Nigel Lawson as a key figure, as well as Cecil Parkinson and Lord Wakeham for seeing it through. On the nuclear industry side, it is clear that John Collier, the first chairman of Nuclear Electric, had a major hand in making the industry competitive, and restoring the fortunes of the maligned AGRs. Bob Hawley, as chief executive of Nuclear Electric, then chief executive of British Energy, provided the energy and determination to drive the industry side through to flotation, just at the end of the Thatcherite tide of privatisations.

1.3. In the fifteen years after 1990, fundamental changes occurred in almost every dimension affecting nuclear power in the UK. The phases are briefly highlighted as follows:

- Break-up of the nationalised electricity industry
- Privatisation
- Market introduction - the pool
- Dash for gas
- Gas linkage to Europe

- Strengthening pool prices
- Privatisation of British Energy
- Weakening pool prices
- Major external companies act as predators on smaller UK companies
- British Energy in crisis seeks government aid
- World oil prices leap100%, gas prices soar, electricity market prices recover

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2. The rationale

2.1. The motivation for privatisations under the Thatcher government in the UK were multiple, but mainly focused on increasing efficiency, delivering lower prices for consumers, and offering more diversity. The arguments of some Conservatives such as Nigel Lawson were lucid and convincing. He argued that decisions for major investments taken by politicians and civil servants are frequently driven by thinking that is far from the economically rational. Furthermore, long periods of domination by huge nationalised monopolies undoubtedly leads to inefficiency of varying kinds. These range from overindulgence in pet projects, to feather bedding and perverse pricing.

2.2. Considerations of this kind led Lawson to commission path breaking work on possible privatisation of electricity when he was Minister of Energy in the early 1980s. But it was naïve to suppose that the invention and imposition of a market, where no market existed before, would necessarily lead to the complete reversal of all the malfunctioning of state-owned dinosaurs. Nor would the fragmentation of the old structures necessarily lead to a halcyon world of busy, inventive, freely competing, entrepreneur led enterprises. It could just as easily lead to the invasion of the 'free market space' by giant oligopolists or monopolists in other areas, who could then carve up the proceeds. This was the end result by 2005.

3. 1990 - Break-up of the nationalised electricity industry

3.1. The old CEGB was broken up in 1990, as was the Scottish system. The Scottish system was split into two entities. The English and Welsh system was broken into a high voltage transmission company, the National Grid, two major fossil fuel generators, National Power and Power Gen, and ultimately a nuclear company, Nuclear Electric, running both Magnox stations, the more modern AGR nuclear stations, and responsible for the partially completed PWR at Sizewell. Furthermore, a mass of 'remnants' from the CEGB, for example research establishments, awkward real estate etc, that could not be easily turned into cash were bundled into the nuclear entity. The downstream regional electricity distributors (the REC's) were sold off individually in 1990, with staged increases in future competition for customers, overseen by the regulator, OFFER. OFFER also sought to limit the market power of the largest generators.

4. 1990 - Privatisation

4.1. Most parts of the electricity generation and distribution system were privatised - at the time, an entirely British experiment. Nuclear elements dropped out of the privatisation basket when it was realised that it would entail a huge cash drain because of historic fuel deals, because of the completion costs of Sizewell, and because of historic poor performance and short remaining lifetimes.

4.2. Low capacity factors achieved in the stations were a particularly obvious problem. The legislative pathway to privatisation was set in the Electricity Act 1989, and the major fossil generators and distribution companies were privatised in 1990.

5. 1990 - The pool and the dash for gas

5.1**.** A market system was invented by government, radically revised, and monitored by a newly created quango, at a short arm's length from government. The first step was to create a market clearing mechanism, setting a price hour by hour for the wholesale market, the ‘pool’, into which the twelve regional electricity distribution companies (RECS) would dip for their supplies. Payments were also available for capacity declared available on the system. Companies could also form longer term hedging contracts bilaterally with the generating companies, linked to the pool price.

5.2. The use of natural gas for electricity generation was permitted in the decade of the 90s under a change of European statute. Initially low natural gas prices stimulated a wave of new combined cycle gas turbines (CCGTs) to be constructed, sweeping into the new market to take over 30% of the total, and triggering the mass closure of UK coal pits and stations. The percentage of electricity generated from gas in the UK total went from 0% in1990 to 36% in 2004, when gas prices began to surge. Even when pool prices had peaked in the mid 90s, capacity in gas, much already committed, continued to grow - the typical ‘overshooting’ to be seen in other volatile commodity markets.

Table B1: The dash for gas

Fuel source	**UK capacity GW**		
	1993	**1996**	**2004**
Modern gas turbines (CCGT)	1.3	12.7	26.6
Nuclear	11.4	12.9	11.9
Conventional steam (coal, oil, etc)	47.9	41.5	34.6
Other gas and oil	2.5	1.5	1.5
Hydro	4.2	4.2	4.2
Renewables, non-hydro	0.2	0.5	1.6
Total	67.5	73.3	80.4

Source :Digest of UK Energy Statistics, DTI, 2005 and 1997

5.3 In the mid 1990s, the UK’s North Sea gas system gradually linked up to a developing European gas network. The south basin of the North Sea gas system was linked via a high capacity pipeline to Zeebrugge, thus making the UK a part of the European gas grid, which stretched from the Netherlands to the major new sources of natural gas in Europe, around the Caspian, and in Russia east of the

White Sea. The northern part of the network was also linked to the UK via pipelines connecting the Norwegian network. Once UK reserves were substantially exhausted, UK prices would inevitably in future be dominated by European prices set in transactions between Russia and the major European players such as EON (which took over Ruhrgas) and Gazprom. Exporters of LNG (liquefied natural gas) will seek to obtain no worse prices than those set by the major European sources.

5.4. Alarm should have started in Whitehall as early as 2003, when Transco experts revealed that their best estimates for UK gas import dependency were 52% in 2010/11, and 70% by 2012/13. This replaced 2002 analysis of 38% and 45% respectively, which should have been alarming enough (Bi)**.**

6. The early years of the market experiment

6.1. In the early days of the pool, prices strengthened, enhancing the financial performance of all the generating participants in the market. World oil prices had no effect on the UK market, since the gas/oil/electricity linkage had not been established through any significant presence of gas generation.

Table B2: Electricity prices in the first pool phase

	1992	**1993**	**1994**	**1995**	**1996**
Price for generators, UK*	2.08p	2.28p	2.44p	2.4p	2.39p
World oil price	$19.2	$16.8	$15.7	$16.8	$20.5

Time weighted average pool purchase price, p/kWh, oil in $ per barrel

Sources :British Energy Prospectus 1996, US DOE 2006

6.2. At the same time that average pool prices were strengthening, the cost performance of the AGR nuclear fleet was improving. For a company in the state sector to achieve this kind of productivity increase was quite exceptional, and a major credit to the organisations under Nuclear Electric plc and Scottish Nuclear. It was achieved whilst improving safety performance (Bii) the paramount issue for all nuclear generation.

Table B3: Improving productivity up to privatisation

Year ending March 31	1992	1993	1994	1995	1996
Operating costs, p/kWh	3.3	2.8	2.5	2.4	2.5
Output per employee, GWh	5.0	6.3	7.3	8.0	9.4

Source: British Energy Prospectus 1996

7. 1996 - British Energy privatised

7.1. On the basis of greatly improved performance for the AGRs, the successful completion and commissioning of Sizewell B, and the massively improved financial results inside Nuclear Electric, a new nuclear entity, British Energy, was created and privatised in 1996, leaving the Magnox stations under state ownership. In its first years of privatisation, British Energy profits soared, and its share price massively increased. John Robb, formerly Chief Executive of the Wellcome pharmaceuticals company, had the brief from Whitehall to create a Scottish-based company. A Scot himself, largely resident in England, he sought to move the maximum number of administrative departments of British Energy to Scotland. This led to the effective dislocation of the management core of the company, and has since been largely reversed. The early profits of British Energy led to some very successful business development in Canada and the USA, where the values of nuclear plant had been substantially discounted. Robin Jeffrey, the former chief executive of Scottish Nuclear, can be credited with these successes.

8. 1990-2003 - Gas dominating

8.1. The ‘dash for gas’ stimulated by the high initial electricity prices, cheap gas and low capital construction costs had added 17GW of new capacity - 40% greater than nuclear - to the system by 1999. Oil prices weakened from 2000, taking down gas contract prices progressively, and assisting an electricity price collapse, bankrupting a number of generators, and taking the privatised nuclear vehicle, British Energy, into crisis. NETA, introduced in 2000 by Energy Minister Peter Hain, seems to have been the final trigger, rather than the root cause.

Table B4: Prices collapse under NETA

British Energy performance	1999/2000	2000/1	2001/2	2002/3	2003/4
Operating profit/loss	£430m	£230m	-£281m	-£3,899m	£340m
Electricity price (pence per kWh)	2.6p	2.3p	2.0p	1.8p	1.7p

Source: Power Engineering Journal, August 2002, and British Energy company report 2005

9. 2002 - Nuclear in crisis

9.1. British Energy was dependant upon base load prices, which suffered a precipitous fall both before and after the major overhaul of the electricity market, the 'NETA'. British Energy could not support its new overseas acquisitions in North America, and was making growing losses on its operations in the UK. The government facilitated loan support. British Energy was then financially restructured and embarked on a series of changes in its top management.

9.2. NETA was supposed to prevent market abuse. One of its side effects was to favour the most flexible plant, which was coal. The consequences for the environment were of course to increase C02 emissions, quite to the contrary of government strategic policy. The following table shows the increase of coal burning in the electricity supply industry after the introduction of NETA at the beginning of 2001. Thus coal burning was nine per cent higher in 2004 than it had been in the last complete year of the old pool system, 2000 (Biii).

Table B5: Coal burning in electricity generation and CO2 emissions

	Year pre NETA	Year post NETA			
	2000	2001	2002	2003	2004
Coal used in generation TWh	333.4	367.6	344.6	378.5	364.4
CO2 emissions, energy industries*	53.8	56.4	55.5	58	na

*UNECE /EMEP nomenclature for reporting

Sources: Dukes, DT!, 2005; DEFRA, 2006

9.3. From 1997 onwards British Energy had experienced almost continuous management turbulence. John Robb, the chairman appointed by Whitehall at privatisation in 1996, presided over the departure of Bob Hawley; the departure of the managing director of BE Generation, Peter Warry; the appointment of Peter Hollins as overall chief executive; the appointment of a new managing director of BE Generation, Mike Low; the departure of Mike Low; the departure of Peter Hollins; the appointment of Robin Jeffrey as, first, chief executive then chairman; and David Gilchrist's appointment as managing director of BE's British nuclear power operations in 2001. All of this compressed into just five years. In 2002 Robin Jeffrey resigned, after the company had sought and obtained urgent support from the DTI.

9.4. The management in British Energy went through rapid changes of personnel before and after the arrival of Adrian Montague as chairman in 2002. Adrian Montague had been at Kleinwort Benson; then chief executive of H.M.Treasury's PFI task force; at Societe Generale; and in 2002, deputy chairman of Network Rail. He was clearly well thought of in the Treasury, and had the credentials of a City heavyweight. In spring 2003, senior management at British Energy could point to seven substantially different patterns of management in the previous seven years - with four different chief executives, three different chairmen, and four different directors of generation for the major fleet of generators. In 2002, Mike Alexander from Centrica was appointed chief executive; in 2004, Roy Anderson from PSEG Nuclear (US) was appointed chief nuclear officer; David Gilchrist resigned in 2004; in 2005 Mike Alexander resigned; and Bill Coley from Duke Power (US) became chief executive.

10. Market liberalisation spreads, but not UK-style

10.1. Europe began in parts to liberalise energy markets. But major governments took no stance against the development of transnational giants, despite traditional competition European policy. Indeed, the process led to a concentration of market power - for example, the takeover of Ruhrgas by the German electricity giant EON.

10.2. The two, giant, early day, English generating companies Power Gen and National Power were bought out by major European electricity generators, as had been many of the regional distribution companies. The English market became much more oligopolistic, the market players bigger, trans-european, and possibly therefore more difficult for future governments to influence. The French electricity giant EDF, mainly owned by the French government, is now a significant owner of UK distribution, as is EON from Germany, with its stake via Ruhrgas in the Russian gas giant Gazprom.

Table B6: Ownership concentration in electricity

Independent companies 1990	Present owners 2006
Eastern	EDF France
East Midlands	EON Germany
London	EDF France
Manweb	Scottish Power
Midlands	EON Germany
Northern Electric	CE elelctric
Norweb	United Utilities
Seeboard	EDF France
Southern Electric	Scottish & Southern
South Wales	PPL USA
South Western	EDF France
Yorkshire	Indep USA
Scottish Power	Scottish Power
Scottish Hydro	Scottish & Southern

Source: energylynx, 2006

10.3. Of the original major privatised generating companies, only British Energy and Magnox Electric remain unlinked to major European transnational companies. The present owner of National Power is RWE (Germany). EON (Germany) owns PowerGen. Nuclear Electric plc is currently owned by British Energy and Magnox Electric.

11. World oil prices surge

11.1. World developments led to a huge rise in crude oil prices from 2002, reaching by January 2006 $65 per barrel, a level in dollar terms well over 200% higher than they had been on average in 1999. These massive rises in world oil prices triggered European wholesale gas price rises and rises in contract prices for UK wholesale gas, feeding through into the UK electricity prices. The reformed British Energy's fortunes improved considerably.

Table B7: World oil prices 1999-2005

1999	2000	2001	2002	2003	2004	2005
$16.6	$27.4	$23.0	$22.8	$27.7	$37.7	$46.5

$ per barrel, source: *US DOE, annual averages 2005*

12. 2004 onwards - Electricity prices follow

12.1. The UK's gas contract prices, linked directly and indirectly to oil, rose sharply, and electricity prices started to rise significantly, due to the new dependence on gas. Gas prices are traditionally linked for very large contracts to oil prices, since over the medium term, the major oil and gas producers can always choose to focus their exploration and extraction activities towards either oil rich or gas rich deposits. The emergence in the longer run of major terminals in the UK for international trade in liquefied natural gas (such as those which have existed in Japan for decades) will not change this phenomenon. January 2006 baseload wholesale prices at 5.5p/kWh were 205% up on those prevailing two years before.

Table B8: Wholesale electricity prices

Typical baseload prices	2003/4	Mar-03	Mar-05	% change, 2003/5
p/kWh	1.7	1.8	3.5	plus 94%

Source: Heren Energy 2005, plus industry sources,rounded

12.2. UK government policy, via the instrument of privatisation, the electricity regulator and its precursors, had clearly been towards breaking up large enterprises, when they were within its power. But the UK electricity market itself has clearly favoured the entry of transnational giants like EON and EDF. The combination of a volatile electricity price, and a system of regulation that neither guaranteed price stability nor an absence of market abuse through oligopoly, created an environment in which only very large market entities, vertically integrated, could successfully survive in the UK.

12.3. Thus trans-european electricity companies, not subject in their domestic markets to the same level of uncertainty and intervention, have moved in to buy large tranches of UK generation and distribution as noted above. Ironically, one of the biggest of these is EDF, the French nationalised electricity giant. It is also one of the world's largest nuclear generators.

13. Reform of fuel cycle and waste reprocessor

13.1. The UK government-owned fuel reprocessor, nuclear engineering and waste processing company, BNFL, was broken up in 2004, to facilitate market innovations. Legislation to create the Nuclear Decommissioning Authority had been passed in 2004 (Bvi). As the climate for potential new nuclear build improved, government sought a sale of the nuclear design company Westinghouse owned by BNFL.

13.2. Thus DTI moved ahead towards tackling long term nuclear waste issues. But DEFRA, with important responsibilities in the same area, showed no signs of determination or urgency, thirty years after the Flowers report. We await the report of the committee on radioactive waste (CORWM) set up in 2003. The very existence of CORWM has the hallmarks of delay. As the House of Lords Select Committee reported on the establishment of CORWM : "The desire of the government to embark on repeated consultation exercises looks increasingly like an attempt to put off taking a decision…We cannot understand why DEFRAs chief scientific adviser was not directly involved in the formation of a committee that will be providing advise to ministers on crucial scientific and technical matters" (Bvii).

14. 2002, 2003, 2005, 2006 Review and review again

14.1. The government reviewed its energy policies in 2002. No great concern was expressed about over-dependence on gas for electricity generation. It decided, paradoxically that the market was working well, but that urgent steps were needed to increase the proportion of renewable energy in the electricity sector. It set a target of ten percent renewable power by 2010 - thus adding, it can be assumed, to overcapacity in the market.

14.2. It was not made explicit clear who was responsible for achieving this target. The RO, bringing Increased subsidies to wind generation, seemed a likely instrument. Meanwhile, it became clear in 2004 that the ambitious UK target of 20% cuts in carbon dioxide (the major greenhouse gas) would not be met. By 2005, extreme concerns about over-dependence on gas supplies from Europe, dominated by Russia, was given as one underlying reason for developing much closer relations between President Vladimir Putin on a state visit to the United Kingdom and Prime Minister Tony Blair.

14.3. Russia's willingness to behave along Western profit-optimising lines was demonstrated in its negotiations with Ukraine at the end of 2005. In January 2006, the Russian gas price to Ukraine was settled at $230 per thousand cubic metres, an increase of more than 300%, after Gazprom had persuasively turned the taps off. This new price represented around 40p/therm from Russia to Ukraine along well-established high capacity pipelines. The price impact to Ukraine was moderated by supplies from Turkmenistan and other Gazprom-linked suppliers. However, the implications for countries hundreds of miles westwards along the supply lines or along new ones, are dramatic.

ENDNOTES

(Bi) John Wybrew presentation at British Management Data Foundation, 2003
(Bii) British Energy Prospectus, 1996
(Biii) Digest of UK energy statistics ('Dukes'), DTI, 2005
(Biv) DEFRA: Environmental Statistics, e-Digest, 2006
(Bv) Heren Energy Ltd
(Bvi) Energy Act 2004, and DTI website
(Bvii) House of Lords Select Committee, Science and Technology, Fifth Report 2004

Appendix C

Relative electricity prices under the UK market experiment

1. The logic of the liberalised market experiment was that innovation and dynamism were required from market pressures to optimise both investment and consumer satisfaction. The theory was that feather bedding state enterprises led to bad decisions, and finally to higher prices for commodities, or less choice in commodities. With electricity, there is no ‘product innovation’. Electricity is electricity, providing it is supplied 24 hours a day at dependable voltages. Innovation and optimum investment matters in so far as it increases dependability, reduces prices or alleviates price rises caused by other external factors. Thus success can be measured almost entirely on the price at which electricity is supplied.

2. Up to 1990 the performance of the CEGB in delivering electricity, reliably, was very good. Its price relative to prices prevailing in other European countries was also good. Excluding taxes, UK electricity prices to domestic consumers were lower than those prevailing in both France and Germany, and only slightly higher than those prevailing in Italy.

3. By 2002, our domestic prices were lower than Italy, but nearly 22 % higher than in France (Table C1). Table C2 shows that for the smallest domestic consumers (for example, pensioner households), our prices are still lower than Germany’s, as they were in 2002 but increasing just as fast; and increasing much faster than those in France. The French case is particularly interesting because the French, as we have seen, have had a very large nuclear programme, are approximately 80 % supplied by nuclear, supply virtually all British imports, and were not carrying out a market experiment.

Table C1: Electricity prices pence/kWh: all domestic consumers, excluding taxes *(percentages based on unrounded figures)*

Country	1990	2002	2004	% increase 90-04
France	6.9	5.5	5.8	-16
Germany	7.5	7.8	na	na
Italy	6.4	6.9	7.5	17
UK	6.7	6.7	7.2	7
% UK higher/lower than France	-2.9	21.6	23.4	

Source: DTI Quarterly Energy Prices, March 2002, December 2005

4. With taxes taken into account, French domestic consumers were slightly worse off than UK customers in 2004, although their prices fell by over eight per cent.

Table C2: Electricity prices pence/kWh: all domestic consumers including taxes *(percentages based on unrounded figures)*

Country	1990	2002	2004	% increase 1990-2004
France	8.4	7.0	7.7	-8.8
Germany	9.2	9.0	na	na
Italy	8.8	10.4	10.4	18.5
UK	6.7	7.0	7.5	12.7
% UK higher/lower than France	-20.9	0.7	-2.2	

Source:DTI Quarterly Energy Prices, March 2002, December 2005

5. The Government has rightly focused on fuel poverty as one of the issues for the Review. The smallest electricity consumers are clearly the most vulnerable to price instability, since a much higher proportion of their disposable income goes on fuel. Table C3 shows that in October 2005 small consumers still paid more for electricity in the UK than in France and Italy. Also, price rises in the UK have been faster than those in France. UK prices for small consumers are around one third higher than those in France before tax. The French taxes on electricity make the gap smaller - but small French electricity consumers still pay five per cent less than their UK equivalent allowing for taxes, on the most recent government data.

Table C3: Electricity prices pence/kWh: small domestic consumers excluding taxes *(percentages based on unrounded figures)*

Country	Jul-02	Jul-03	Jul-05	% increase 02-05
France	7.2	7.6	7.6	5.3
Germany	9.3	10.4	11.8	28.0
Italy	5.0	5.7	5.8	17.5
UK	9.1	8.9	10.2	12.9
% UK higher than France	25.5	17.2	34.7	

Source: DTI Quarterly Energy Prices, December, 2005

6. When taxes on electricity are included, UK prices are still higher for small domestic consumers than those in France and Italy, and increasing faster. The adverse gap between French and UK prices is increasing.

Table C4: Electricity prices pence/kWh: small domestic consumers including taxes *(percentages based on unrounded figures)*

Country	Jul-02	Jul-03	Jul-05	% increase 02-05
France	9.4	10.0	10.2	9.5
Germany	12.1	13.7	15.4	27.3
Italy	6.4	7.0	7.0	10.7
UK	9.5	9.4	10.8	13.2
% UK higher/lower than France	1.6	-5.8	5.0	

Source: DTI Quarterly Energy Prices, December, 2005.

7. Table C5 shows that the adverse position of UK industrial consumers versus their French counterparts has increased since the electricity market experiment began. This is true before and after tax, and was true in 2004, before the latest oil price effects began to bite. As we would expect for an energy rich country, the UK is still less expensive than some other major countries such as Italy and Germany. However, the market operation does not show a startling improvement for industrial consumers.

Table C5: Electricity prices pence/kWh: industrial consumers *(percentages based on unrounded figures)*

Country	Excluding taxes			Including taxes		
	1990	2002	2004	1990	2002	2004
France	3.2	2.4	2.4	3.3	2.4	2.7
Germany	4.7	3.2	na	5.1	3.2	na
Italy	4.2	5.7	6.8	5.5	7.5	8.8
UK	4	3.2	3.4	4	3.5	3.7
% UK more expensive than France	25.6	31.1	41.9	19.5	41.8	34.6

Source: DTI Quarterly Energy Prices, March 2002, December, 2005

7. If we examine the most recent developments in industrial prices for Europe, we see that in the last two years, the UK has experienced bigger price increases than its neighbours. For large and extra large industrial customers, the UK prices to October 2005 were up over 50% on their levels in July 2003. Competitors in France, Germany and Italy experienced much smaller increases. For the UK's small industrial customers, the increase was 35% over the same period. The following table shows the situation for medium industrial consumers over this recent time period.

Table C6: Electricity prices pence/kWh: medium industrial consumers *(including taxes,percentages based on unrounded figures)*

Country	Jul-03	Oct-05	% increase
Austria	3.95	4.55	15.2
Belgium	3.98	5.00	25.6
Finland	3.78	3.63	-4.0
France	3.40	3.51	3.2
Germany	4.50	5.85	30.0
Italy	6.17	6.79	10.0
Spain	3.49	3.53	1.1
Sweden	2.60	3.30	26.9
United Kingdom	2.92	3.95	35.3

Source: DTI Quarterly Energy Prices, December, 2005

9. The conclusions from these figures are:

- At the beginning of the electricity market experiment, domestic consumers in the UK were paying rather less than those in major European competitor countries- considerably less than those in Germany and France. Industrial customers were paying more than those in France by over 19%.

- In the most recent phase of the market, fifteen years on, small domestic customers (including tax) are paying more than those in France and Italy. In 2004, industrial customers in the UK were paying, on average, over 30% more than those in France. In the last two years, UK industrial consumers have experienced the biggest electricity price rises in Europe.

- There are no signs of a uniform benefit to domestic customers from the UK experiment. Small consumers are relatively worse off. Industrial consumers have become considerably worse off than their competitors in France, a nuclear strong country with no liberalised market. The UK's heavy dependency on gas is making things worse.

Appendix D: Authors' biographical details

Adrian Ham was chief economist at Nuclear Electric plc from its creation in 1990; and director of consultancy services at British Energy International plc, directing projects in US, Czech Republic and EU/TACIS-financed projects in Ukraine and Russia until his appointment as chief executive at the Nuclear Industry Association. He left to work as an independent consultant in 2003, and was subsequently on BNFL's Nuclear Investment Climate Advisory Board. He has previously worked at the OECD in Paris, and in Chancellor's Office, H.M.Treasury.

Dr Robert Hall has been continuously associated with the civil nuclear industry since graduating from Birmingham University in 1956. After a career within the CEGB and the successor nuclear companies, where for some 14 years he was a member of the nuclear power station safety committees, he retired in 1993. Since then he has been an independent consultant in nuclear safety to various organisations. In this capacity he was for nine years a member of the HSE Advisory Committee on Nuclear Safety (now called the Nuclear Safety Advisory Committee), and since 1993 has been, and remains, a consultant to the Ministry of Defence (RN).