THE ROYAL SOCIETY

THE ROYAL ACADEMY OF ENGINEERING

Nuclear energy

the future climate

Summary report

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Foreword

A secure supply of energy is fundamental for modern society. One might therefore expect energy policy to be the constant subject of intense public debate. The fact that, at least in the UK, it is not, may mean that on the whole our energy policy works. We do not worry particularly about the lights going out.

But energy policy is both a long-term and a global issue. Society requires an energy supply that can meet growing demand and that is reliable, economically affordable and sustainable in terms of its global and local environmental impact. These are major challenges, and there is nothing inevitable about future success. Energy does need to be centre stage in policy-makers' minds.

The Royal Society and The Royal Academy of Engineering therefore set up a joint working group to examine one aspect of energy policy where there is a powerful temptation to procrastinate: the role of nuclear energy in generating electricity. This has been given extra prominence by the Kyoto commitments on emissions of greenhouse gases in general and carbon dioxide in particular. Our aim has been to survey the full range of current and potential technologies for generating electricity and, against that background, to form a view on the future role for nuclear.

The CO_2 issue ***is*** real and increasingly urgent; the many emerging forms of renewable energy ***do*** merit substantial levels of R&D investment and could well become key parts of the UK strategy for sustainable energy supply; initiatives to promote efficiency and conservation ***do*** have a part to play. But, in the light of this study, the Royal Society and The Royal Academy are convinced that it is vital to keep the nuclear option open. We view with great unease current policies that appear unperturbed by the prospect of all nuclear capacity disappearing from the UK by the middle of the next century.

In order to make our analysis and conclusions accessible to a wide readership, we have produced this shortened version of the full report for free distribution. It may also be found on our web sites: royalsoc.ac.uk and raeng.org.uk. The full report (c 80 pages) is obtainable from the Royal Society. We look forward to a serious debate about its practical recommendations on how to develop secure energy supplies in ways that are sustainable in the long term.

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June 1999

Summary

- There is a strong case for acting to mitigate the threat of drastic climate change associated with unrestrained increases in emissions of greenhouse gases, particularly CO_2. Just waiting to see what happens to the atmosphere if we persist with business as usual in electricity generation is not a sane option.

- We must consider exploiting all possible approaches, including using less electricity, using technologies based on renewable sources, and finding ways to prevent CO_2 reaching the atmosphere, as well as exploring the nuclear option. It is not appropriate to dismiss an energy source on the grounds that it could supply 'only' a few percent of need.

- It is vital to keep the nuclear option open. We cannot be confident that the combination of efficiency, conservation and renewables will be enough to meet the needs of environmental protection while providing a secure supply of electricity at an acceptable cost. It is essential to win back public confidence in this option.

- We therefore endorse the 1998 recommendation of the House of Commons Trade and Industry Committee that: 'a formal presumption be made now, for the purposes of long-term planning, that new nuclear plant may be required in the course of the next two decades.' We would further urge that the timetable for such considerations should allow a decision to be taken early enough to enable nuclear to play its full, long-term role in national energy policy. This is likely to mean early in the next administration if a damaging decline in the role of nuclear is to be avoided.

- The planned levy on the use of energy is deeply flawed. Since the objective is to reduce CO_2 emissions, the levy would be much more effective if it was based directly on net CO_2 emitted rather than, as proposed, on the amount of energy supplied.

- There is a need for major investment in research and development in all energy sectors. Because of the long-term and international nature of such work, we propose the formation of an international body funded by contributions from individual nations on the basis of GDP or total national energy consumption. The body would be a funding agency supporting research, development and demonstrators elsewhere, not a research centre itself. Its budget might reasonably build up to the order of $25 billion pa, roughly 1% of the total global energy budget.

Background

1 Energy is one of the most critical resources for modern society. At a global level, we can expect our consumption of energy at least to double in the next 50 years and to grow by a factor of up to five in the next 100 years as the world's population increases and as people seek to improve their standards of living. Even within the UK, with a mature economy and relatively stable population, we can expect an increase of at least 25% by 2020. At present levels of consumption, our use of energy poses threats to the climate, with potentially severe environmental consequences; given the levels of consumption likely in future, it will be an immense challenge to meet the global demand for energy without unsustainable long-term damage to the environment.

2 This situation has attracted the attention of political leaders across the world, and at the Kyoto meeting of the parties to the UN Framework Convention on Climate Change in December 1997 there was agreement to tackle one aspect - the amount of greenhouse gases emitted to the atmosphere. The levels of atmospheric CO_2, for example, have increased from 285 ppm before the industrial revolution to about 350 ppm now. It is now generally accepted that there is a strong case for acting to mitigate the threat of drastic climate change associated with the unrestrained continuation of this trend. The Kyoto meeting produced pledges by the industrialised nations to cut their anthropogenic greenhouse gas emissions, by 2012, to an average of 5% below the 1990 levels. The UK went further, and undertook to reduce its CO_2 emissions by 20% by 2010. Although we have already made substantial progress in this direction, largely as a result of the switch from coal to gas in power stations, we face some major decisions about energy strategy in the not too distant future.

3 As a practical contribution to these decisions, the Royal Society and The Royal Academy of Engineering undertook a study of the technical options available to policy-makers. The study group was chaired by Sir Eric Ash, FRS, FREng (Treasurer, Royal Society); other members, drawn from a wide variety of backgrounds, were Dr Mary Archer (Chairman, National Energy Foundation), Sir Alan Budd (member of the Monetary Policy Committee of the Bank of England), M Rémy Carle (formerly Deputy Chairman, Electricité de France), Sir John Cullen, FREng (formerly Chairman, Health and Safety Commission), Mr Brian George, FREng (Managing Director, Projects, GEC Marine), Dr John Hassard (Reader in Physics, Imperial College), Sir Martin Rees, FRS (Royal Society Research Professor) and Professor Ian Shanks, FRS, FREng (Science Adviser, Unilever Research). This summary records their main conclusions, which have been endorsed by the Councils of both bodies. The full report may be obtained from the Royal Society, price £20.

4 The study concentrated on one aspect of the issue: the present and likely future options for generating electricity in the UK and, in particular, the nuclear option. It is our conviction, underpinning all our work, that just waiting to see what happens to the atmosphere if we persist with business as usual in electricity generation is not a sane option. Predictions in the energy business have a poor track record, but we do know enough about environmental science and about economics to assert that wishful thinking is an inadequate response to the present situation.

Non-nuclear options

5 There are three basic non-nuclear approaches to reducing the emission of CO_2 associated with meeting our demand for electricity: to use less electricity (through measures to improve efficiency, to conserve energy and to reduce demand by changes in lifestyle); to use technologies based on renewable energy sources that lead to no, or no net, emission of CO_2; and to stop the CO_2 reaching the atmosphere (sequestration). Sequestration in biomass could also be used to remove CO_2 from the atmosphere.

6 Wise policy is not a matter of deciding which of these approaches is best and concentrating all our efforts on that. Rather, we must consider exploiting all three approaches to the full: each has a contribution to make. It is not appropriate to dismiss an energy source on the grounds that it could supply 'only' a few percent of need.

7 On energy conservation, for example, applying existing technologies to improving the end-use efficiency of domestic installations and industrial processes in the UK could reduce energy consumption in these sectors by 20% to 25% respectively, in cost-effective ways. Continuing gains in the efficiency of power stations coupled with the progressive move from conventional coal-fired plants to combined cycle gas turbine technology could lead to substantial improvements in efficiency.

8 The main renewable technologies are hydro, wind power, wave power, tidal power, biomass, energy crops and biofuels, passive and active solar heating

and cooling, solar thermal electricity, photovoltaics and geothermal power. Commercial use of many of these technologies is still in its infancy, and they are just starting to make a significant impact on commercial energy supply and consumption. Some renewables (wind, hydro, photovoltaics) supply only electricity, some (passive solar) only heat, while others (biogas and biofuels) can supply either heat or electricity, and transport fuels as well. In addition to their lack of CO_2 emissions, most renewables have the advantage of encouraging decentralised generation and thus reducing the need for further transmission lines.

9 Some of the renewable sources are intermittent - solar of course, but also wind energy. Extensive reliance on such sources then implies the need for energy storage. More usually, one will plan on combining an intermittent source with one that is controllable (fossil, hydro or nuclear), though this has cost implications.

10 Hydroelectric power supplies about 3% of the world's energy. As world demand for energy grows over the next 50 years, hydroelectricity just might continue to contribute 3% of the total, despite the fact that it typically takes up 1000 km^2 of land per GW generating capacity and in some countries is rejected or even banned for environmental reasons. We do not envisage much expansion of hydroelectric supply in the UK.

11 Direct solar power for buildings and, to a lesser extent, solar photovoltaic power may make modest contributions even in the UK, the latter particularly in remote locations where small amounts of electricity are needed and connection to the grid is impractical. A photovoltaic array currently needs 20 km^2 per GW generating capacity and operates in excess of 15% efficiency with single crystal silicon cells and 9% with cells made from the cheaper amorphous silicon. There are hopes of major advances with different materials and new growth and substrate technologies, but photovoltaic power is likely to remain a niche technology in the UK.

12 Wind power is beginning to make a significant contribution. The total installed capacity in the UK is now 330 MW, and in Europe as a whole is 6.3 GW; average energy availability is about one third of these figures. There are major obstacles to rapid growth, but a contribution to generating capacity for Europe approaching 10% is a real possibility.

13 Biomass recycling is of great importance worldwide, currently contributing 14% to final use energy requirements, mainly in developing countries. The opportunity for a major use of biomass in developing countries exists - again though with significant obstacles with regard to competition for land use. A figure of 5% for Europe may be achievable. There are exciting opportunities for enhanced biomass systems with genetically modified plants, if any safety issues can be addressed and public fears of genetic modification subside.

14 Extraction of energy from tidal flows is in practice possible only at sites with relatively high tide differences and suitable estuary geography. It has been estimated that in the UK it might ultimately prove possible by this route to generate the equivalent of a continuously operating 25 GW station, though neither economic viability nor environmental acceptability have been demonstrated. Wave power, similarly, appears feasible in principle, but so far there has been no demonstration project at significant power levels on which to base projections about the potential of this approach.

15 Carbon sequestration involves preventing CO_2 reaching or remaining in the atmosphere, either by photosynthesis (eg by growing trees) or by capturing it directly and storing it in geological formations such as depleted oil wells or deep aquifers. The continuing destruction of forests is actually negative sequestration; to reverse this would require commercial encouragement, a massively increased planting regime or, possibly, a breakthrough in discovering genetically modified species that grow well in inhospitable areas (though this could have knock-on effects for local biosystems). There are some prospects for sequestration of CO_2 in geological formations, or in the oceans, but in the absence of large-scale experiments major technical and economic uncertainties remain.

16 All these approaches are important, now or, potentially, in the future. They should remain, or become, central elements in UK energy policy. The most recent estimate of the potential contribution of renewables, published by the Department of Trade and Industry in March 1999, is that they could meet 10% of the UK's energy needs by 2010. However, it is not at all clear whether the combination of efficiency, conservation and renewables will be enough to meet the needs of environmental protection; and it is clear that for them to make significant inroads will require very substantial investment in research and development.

Nuclear options

17 Nuclear power is not a renewable source in the conventional sense, but it shares with renewables the virtue of not emitting CO_2. At present 31 countries make some use of nuclear energy for electricity generation. Of these 17 rely to more than 25% on nuclear energy: the UK figure is 27% (50% in Scotland). There are 428 reactors currently operating in the world, with a further 35 reactors in the process of construction.

18 The UK has 35 operating nuclear reactors, of which the most recent (Sizewell B) came on stream in 1995. No further nuclear reactors are currently planned. If that situation persists, the UK nuclear generation capacity could decrease to 30% of its present level by 2020 and to zero by about the middle of next century, because of the limited design life of the reactors.

19 We therefore endorse the 1998 recommendation of the House of Commons Trade and Industry Committee that: 'a formal presumption be made now, for the purposes of long-term planning, that new nuclear plant may be required in the course of the next two decades.' We would further urge that the timetable for such considerations should allow a decision to be taken early enough to enable nuclear to play its full, long-term role in national energy policy. This is likely to mean early in the next administration if a damaging decline in the role of nuclear is to be avoided.

20 The nuclear industry is based primarily on uranium, which is about as abundant as tin. At the current rate of usage (50 000 tons pa) and current prices, known economically recoverable reserves of uranium are sufficient for 80 years. This figure could be greatly extended: by allowing the price of uranium to rise (which would have an insignificant impact on the cost of nuclear energy, since the raw material accounts for only 2% of the total energy cost); by recycling fissile materials recovered by reprocessing used fuel; and by exploiting new sources such as lower grade ores or even possibly seawater (which is estimated to contain a total of 4000 million tons of uranium). These approaches are not unproblematic, but serious lack of uranium is not likely to be the biggest challenge facing the nuclear industry over the next 50 years. Moreover, current work on certain types of new reactor is based on using thorium rather than uranium as the fuel, and thorium appears to be more plentiful than uranium.

21 A bigger challenge, much aired in recent debates, is the problem of waste disposal. While there is not great urgency with this, we agree with the March 1999 House of Lords report, that phased disposal in a deep repository is feasible and desirable, especially if the waste remains retrievable. We accept that there is time to explore this more thoroughly before taking the plunge. We would also wish to keep open the door to disposal deep under the sea floor, by an internationally collaborative programme of research at an appropriate point in the future.

22 There have been significant advances not only in the basic design of new nuclear plants but also in retrofitting of improvements into older plants, in operational practices, procedures and training. The advances in fuel technology are particularly important - the total output per kg of fuel has more than doubled during the course of the last 20 years. There are several ideas for major innovations in the design of nuclear power stations. What characterises all of them, with the exception of the search for fusion energy, is the relatively low level of current R&D investment, which seems out of scale with their potential future importance.

23 There are, broadly, three types of safety issue associated with nuclear power: the risk of a catastrophic accident releasing uncontrolled amounts of radioactive material into the environment, any risks associated with radioactive leakage in daily operation, eg from plants or from stored waste, and the possibility of proliferation. It is not difficult to show that counting all risks from uranium mining to (surface) storage of spent fuel, the number of casualties per kWh has so far been much less than for electricity generated with fossil fuel. Whilst reassuring, that observation does not in itself dispose of the problem. In a situation where an extremely unlikely event would have extremely undesirable consequences, statistics provide only limited comfort. However, within the limits of human endeavour, we believe that the regulatory and inspection regime in the UK, which addresses both the construction of nuclear power stations and their daily operation, is highly rigorous and well adapted to the needs of a democratic society.

24 The international safeguards to prevent unauthorised diversion of fissionable materials, in the major nuclear energy countries during the last few decades, have been rigorous and effective, with some reservation about the Former Soviet Union. We have no concerns, on grounds of danger of proliferation,

with the maintenance or moderate expansion of nuclear power in OECD countries. If however one were to look to nuclear power as a major part of the answer to the growing energy problem, the increased danger of proliferation is a factor that would have to be examined with the greatest care.

25 One safety issue that gives rise to much controversy is whether there is a threshold below which ionising radiation causes no significant damage to human tissue. Safety limits are currently set on the basis that there is no such threshold; this is intended to produce an upper limit to the risk of radiation damage, and results in substantial extra expenditure. But there is a body of authoritative opinion, including the French Academy of Sciences, that a radiation threshold does exist below which the possibility of radiation damage can be ignored. The only way of establishing the existence, or absence, of a threshold appears to be a major international epidemiological study. We recommend that means be found for carrying out such a study.

Economic and social issues

26 The cost of using fossil fuels takes no account of the way the atmosphere is used as a free dump for CO_2 or of the resultant environmental damage, and conventional market forces cannot rectify this. The economic tools available to address this include voluntary agreements, regulation and various instruments. The first two are unlikely to be both effective and equitable. Economic instruments were examined in a report published by a Government task force in November 1998, and include tradable emission permits and taxation. Between these, we see taxation as the preferable approach. In March 1999 the Chancellor of the Exchequer announced his intention to introduce a climate change levy on the business use of energy. We believe this proposal to be deeply flawed. Since the objective is to reduce CO_2 emissions, we believe that the levy would be much more effective if it was based directly on net CO_2 emitted rather than, as proposed, on the amount of energy supplied. As demonstrated in the March 1999 DTI report on renewable energy, a carbon tax of the order of one p/kWh on the price of electricity generated from fossil fuels would have a major impact on the viability of the main renewables.

27 In all the technical approaches to the CO_2 problem discussed in our report - the various renewables, sequestration, and nuclear - the amount of research and development work going on at national and international level is substantially less than the importance and urgency of the problem warrant. We believe that very large research resources are needed. These will need to come from the public sector because of the long timescales involved. Since world climate is at stake, the public sector funding should have an international dimension.

28 What we propose is the formation of an international body focused on opening up energy options and funded by contributions from individual nations on the basis of GDP or total national energy consumption. The body would be a funding agency supporting research, development and demonstrators elsewhere, not a research centre itself. Its budget might reasonably build up to the order of $25 billion pa, roughly 1% of the total global energy budget. The UK share of this would be around $450 million.

29 Energy policy is rightly a matter of immense public interest. Any discussion of energy policy must therefore pay close attention to public concerns. The most obvious concern that the public has about energy policy is that it should work. In the present context, that means that electricity should be available on demand, to every user, every minute of the year, at an affordable price. This concern may not feature very visibly in a debate dominated by the perceived environmental and political problems associated with current strategies for meeting that demand, but it is well understood by the politicians.

30 Society must accept responsibility for balancing the constraints it places on the electricity suppliers against the demands it makes for their product. In that sense, getting energy policy right is everyone's responsibility. It is clear, therefore, that communication among those responsible for energy policy – consumers, suppliers, regulators – is central to successful practice of the art of the possible. Today's mistrust has built up over the last two decades, and will not quickly be turned around.

31 The first requirement is for the nuclear industry to be genuinely open and accountable. The UK industry's performance in this regard is now better. Nonetheless it remains a challenge in that all explanations of plans, and comments on operations, have to be bilingual - they have to make sense both to the source and to the intended recipients of the information provided. The regulatory bodies such as the Health and Safety Executive should make even

greater use of public consultation to establish consensus on key issues. The nuclear industry should also think more closely about risk/benefit analysis and public attitudes. Objective risk analysis looks at mathematical probabilities; public opinion looks at who bears the risk and who reaps the benefit. There may be scope for the industry to do more to share the benefits with those who perceive themselves to be carrying the risk, a policy which has been implemented with a considerable measure of success in France.

32 Another area of communication among the stakeholders is the formal planning inquiry. In recent years this has become a forum for almost ritual rehearsals of the full panoply of arguments, at great cost in time and money to the consumer. The process does little to take forward the core issue of balancing responsibility for demanding electricity with responsibility for placing appropriate constraints on the electricity generators. The inquiry for Sizewell B which took three years and cost - before the first sod was turned - £30 M, cannot be seen as an appropriate form of decision-making. There must be a better way! At the least, the local planning stage should be limited in time to the extent commensurate with local democracy.

33 Public confidence is central to the future of the nuclear enterprise, as everyone now recognises. Such confidence cannot be demanded: it must be won by a mixture of openness on the part of the industry, acceptance of a degree of responsibility by the public, recognition of long-term self-interest, and clear leadership by politicians. None of these are quick or easy, but they must be worked at if we are going to keep the nuclear option available.

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Energy and the environment (submission to the Royal Commission on Environmental Pollution, February 1999)

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