IS THERE A CASE FOR NUCLEAR POWER?

by
Sir Martin Ryle F.R.S., F.Eng.

"The Government's proposed nuclear programme would only make an insignificant contribution to the energy which will be lost by oil/gas depletion, and it is extremely urgent to put in hand other programmes which can make an effective contribution. The immediate attention to saving energy now wasted, the installation of district heating schemes in urban areas and a modest introduction of renewable energy sources could, by the end of the century, replace most of the nontransport uses of oil, without increasing our present coal production."

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Is there a case for nuclear power?

Before proceeding with the 1979 programme to build 15 GW(e) of nuclear power stations by the year 2000, it is important to re-examine the original purpose of the nuclear-power programme, (to fill the energy gap), and see how far these aims are likely to be achieved. It is necessary to look at the end uses of UK energy demand and explore the possibility that these might more realistically be met by alternative energy programmes

by Sir Martin Ryle, F.R.S.

The R&D costs of the past nuclear programme have been very great (some £2500 million over 25 years excluding fast breeder and fusion research) yet it provides us (1980) with only 1·5% of our energy (11·8% of electricity, which represents 13·4% of the total).[1] None of the reactors developed seems likely to be used in the new programme, for which a modified version of the US Westinghouse PWR is being proposed (despite unresolved safety problems[2,3] and the need for still greater safety in the tenfold higher population density around UK sites compared with those in the USA). Problems of long-term disposal of radioactive waste[4] and of dismantling a large reactor at the end of its life remain.[5,6] The latter may be accentuated if the recent realisation of the presence of the long-lived Niobium-94 in irradiated US reactor steel occurs in the UK version.[7]

End-use needs

In this article 'delivered energy' is used to describe the energy supplied to, and paid for, by the consumer; it is more meaningful than describing different sources in terms of an equivalent 'primary energy', which in the case of electricity includes the large proportion dissipated in atmosphere or sea. Account must also be taken of differences in the 'end use' efficiency — i.e. how the consumer uses the energy he has paid for.

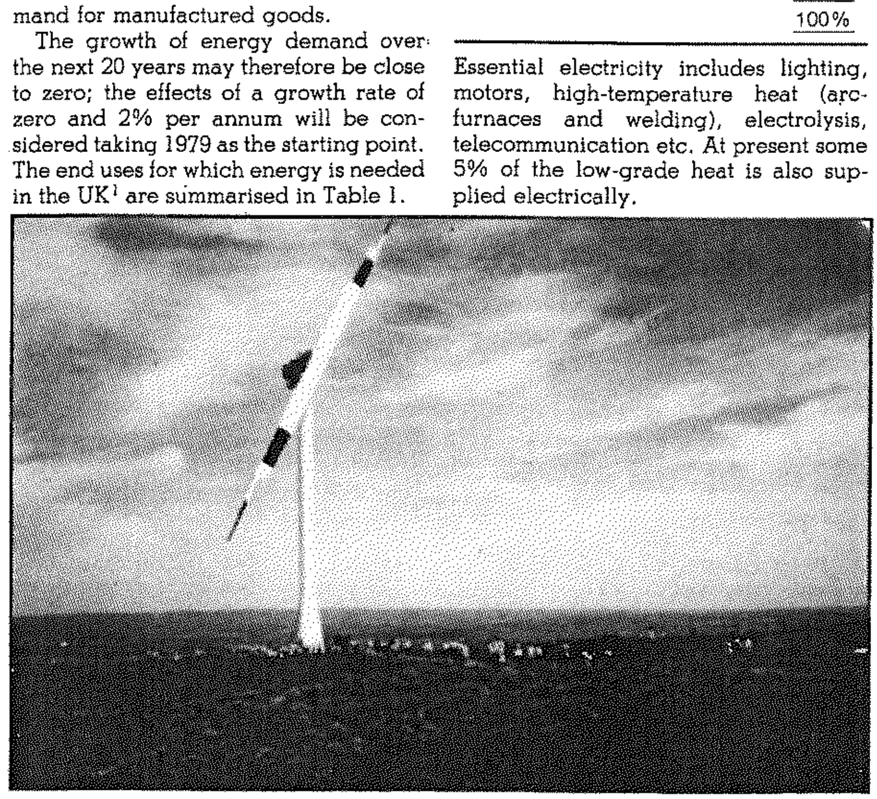
It is difficult to predict the effects of the present world recession; in the UK, competition (not only in our traditional manufacturing industries, but also in new areas such as microelectronics and computers) is becoming acute from newly-industrialised nations, many having a lower standard of living than ours. It is therefore difficult to see how our products can be competitive in the export market, and so allow a significant expansion of our industrial output, without a general lowering of living standards; this in turn will reduce home demand for manufactured goods.

The growth of energy demand over the next 20 years may therefore be close to zero; the effects of a growth rate of zero and 2% per annum will be considered taking 1979 as the starting point. The end uses for which energy is needed in the UK[1] are summarised in Table 1.

Table 1 Energy end uses

heat		
< 100°C	55%	66%
100°-600°C	6%	
> 600°C	5%	
transport fuels		26%
essential electricity		8%
		100%

Essential electricity includes lighting, motors, high-temperature heat (arc-furnaces and welding), electrolysis, telecommunication etc. At present some 5% of the low-grade heat is also supplied electrically.



1 One of three 2·5 MW(e) wind machines installed on the Bonneville Power System, Washington, USA. The rotor, supplied by the Boeing company, is 300 ft in diameter

The sources of the delivered energy (1979) are shown in Table 2.[1]

Table 2 Sources of delivered energy

oil	44·4%	71%
gas	26·6%	
solid fuels (direct heat)		16%
electricity		13%
		100%

During the 1970s, estimates of the date by which world oil supplies would fail to meet demand were made by eight national and international agencies; the mean date was 1987, a figure similar to that suggested at a conference on Energy at the Royal Society in 1974.[8] Subsequently, the price of oil will rise — which both tends to reduce demand and to encourage the development of smaller or otherwise less economical fields. UK continental-shelf reserves have been estimated to provide UK demands at zero growth for about 21 years.[9]

A more recent world survey[10] gives (for noncommunist countries) the growing world demand and decreasing 'proven' reserves. The situation has been temporarily alleviated by the recession in manufacturing countries, and new fields will most probably be discovered, although many of these are likely to be in Third World countries where their development may be politically difficult. But whatever supplies become available it is certain that many developing countries will demand a fairer share of the remaining reserves.

It is doubtful if our descendants will forgive us for continuing to extract, today, at a rate sufficient to cause the present 'glut' of a resource of such value as chemical feedstock; it is also indefensible that governments do not impose limits on extraction rates when the real value will so obviously continue to increase.

Similar arguments apply to the extraction of natural gas, where figures for the present consumption and estimated reserves from the continental shelf show a slightly longer life[1], but one in which conservation is vital. The construction of a gas pipeline to the northern North-Sea fields would allow the collection of gas both from existing fields (at present being 'flared-off' at a value of £1 million per day) and new fields; it would provide a total energy about the same as that from the entire 15 GW(e) nuclear programme during the lifetime of the reactors. The government refused to support the construction of this pipeline even though its cost would have been about one-tenth that of the nuclear programme.[11]

One must conclude that within the next 20 years there is likely to be a major increase in the cost of oil and gas, and that unless we can reduce our dependence on these fuels, our industry will become still less competitive and our way of life poorer. Oil and gas used as chemical feedstock may absorb the higher costs, as may certain (e.g. some transport) uses, but as a general fuel we must plan to replace a major part of it by the end of the century and most by about 2025. For every year earlier in its replacement as a fuel, our descendants will have some 15 years more use as chemical feedstock.

Substitution by electricity

An analysis of the uses to which oil and gas are put was made in an earlier paper,[12] in order to examine the diurnal, annual and intermediate variations of the total energy demand. From these figures the peak demand (and hence installed generating capacity) and total electrical energy (and hence fuel) needed to provide an electrical substitute can be derived. Because of the large fluctuations in demand it was also assumed that two-thirds of building and water heating could be provided by storage systems, and that 75% of road-transport could be based on off-peak electricity (either using hydrogen in fuel cells or IC engines, or with improved batteries). But even with these assumptions, the diurnal variation of demand is still extremely large (~5:1 in winter) and no method of storage yet envisaged appears to have any hope of providing that required, (some 1·2 TWh on a 24 h cycle — or nearly 100 times the present total UK storage)

The slow progress in the development of electric road transport makes it unlikely that much will exist by the year 2000, but it does not in any case affect the installed capacity needed.

If oil and gas were to be replaced by electricity these results showed that in 1975 an additional installed capacity (with an assumed load factor of 70%) of some 233 GW(e) would be needed. Scaled for 1979 consumption the figure becomes 258 GW(e).

Table 3 Available nuclear capacity expressed as a percentage of that needed to replace present oil/gas demand (258 GW(e) at 70% load factor)

	zero demand growth rate		2%/year growth rate	
1980	2·3		2·3	
1985	3·7		3·3	
1990	3·5		2·9	
1995	2·9	(3·3)	2·2	(2·5)
2000	2·5	(4·7)	1·7	(3·2)
2005	5·6	(7·5)	3·4	(4·6)
2010	5·3	(5·3)	2·9	(2·9)
2015	5·0	(5·0)	2·5	(2·5)
2020	5·0	(5·0)	2·3	(2·3)
2025	5·0	(5·0)	2·0	(2·0)
2030	4·6	(3·2)	1·7	(1·2)

After 2025 the available capacity decreases.

Nuclear power stations

The problem of cracks which have occurred in reactor vessels and pipe/duct work seems to suggest that there may be a major difficulty in meeting the fluctuating demand described above. Unless the redesigned PWR is fatigue-proof over its designed lifetime on a 24 h cycle, the only alternative would appear to be dumping of the unwanted energy at times of low demand — thus increasing the fuel needs by a factor of about 2½.

But even if a solution were found, the installed capacity needed is far beyond that envisaged by the Department of Energy. In Table 3, the nuclear capacity available at different dates is expressed as a precentage of that derived as being necessary to provide the present use of oil and gas. These figures are based on the assumption that 1·11 GW(e)[13] of new capacity is built every year starting in 1983.*

The load factors (more strictly the product of downgrading and winter availability) for the Magnox stations of 54%[15] with the probability of some further downgrading and final closure by 1995[15] are assumed.

Although three stations of the earlier ordering of AGRs (Dungeness, Hartlepool and Heysham I) remain incomplete after 13, 15 and 16 years construction time, respectively, despite an estimated 5-6 years, it will be assumed that they will be completed within a year or two. For neither Magnox nor AGR is there any evidence for a 'learning curve'. The two new AGRs will be assumed to have a build time of 10 years, and all AGRs are assumed to have a lifetime of 25 years[16] with a life-time load-factor of 60% (despite the initial 43% and 52% for Hinckley Point B and Hunterston B).

A build time of the prototype PWR (Sizewell B) has been estimated as 6-7 years[17] after planning approval. In view of past history and the fact that this is a redesigned reactor of a type unfamiliar to much of the UK nuclear industry this seems unrealistic, and a 10-year build time is assumed. For future PWRs a construction time of 8 years is assumed with 2 years for planning inquiry and contracts. A lifetime of 30 years is adopted, although there have been additional faults in US reactors since the NRC report (replacement of tubes in steam generator after 8 years due to corrosion and, more seriously, radiation-induced brittleness in pressure vessels); the latter is evidently not, as claimed, limited to reactors built of certain steels or using copper-rich weld material.[18,19]

*Even if a successful fast-breeder-reactor prototype were built within the next 10-15 years and further manufacturing effort were available, the long 'breeding time' now envisaged makes an FBR programme dependent on the plutonium from the thermal programme. The limited quantities of this material mean that the contribution of FBRs is not important on the time scale considered.[14]

The load factor of US Westinghouse PWRs is 52%, while a CEGB survey of large (> 1 GW(e)) Westinghouse reactors, worldwide, gave a figure of 46·7%.[20] A possibly optimistic figure for the lifetime load factor of 60% will be assumed.

These figures may now be assembled to establish the nuclear capacity available at different dates. They are expressed as percentages of what would be needed to substitute for present oil and gas consumption. The extensive modifications necessary to the original Westinghouse design suggests that Sizewell B should be regarded as a prototype and that further stations should not be built until it had been in operation. If construction of further stations were to proceed without this precaution, more stations would be online sooner and a higher initial energy would be available; the corresponding figures are shown in brackets. It must, however, be remembered that such a procedure might involve modifications after construction had started with a consequent extension of the build time.

The figures above assume that electricity demand continues to be provided as at present — the bulk being from coal stations. If the present policy of premature retirement of coal stations in favour of nuclear continues, the figures are reduced significantly. If this replacement were to reach 30% of the present total installed capacity, all the figures in Table 3 become negative, and no nuclear contribution to the depletion of oil and gas is possible.

Coal-fired stations

A solution based on increasing the capacity of coal-fired stations would involve a four-fold increase in coal production, which appears impracticable in view of the time taken to build new mines, shortage of skilled workers and limited progress in automatic coal cutting, underground burning etc; it would also involve the construction of some 250 GW(*e*) of new generating capacity, and improved pollution control.

It is therefore concluded that no electrical solution to oil/gas depletion is possible in the time available, and that alternative energy programmes must be found. Their subsequent development may provide a better long-term solution than any nuclear developments.

Alternative programmes

Alternative energy programmes, taking account of the wide range of end-use needs, are here considered under three headings:

- The saving of energy at present wasted
- The use of district heating (DH) schemes
- The introduction of renewable energy sources.

All three areas have suffered from a lack of Government R&D funding, virtually nonexistent until 1977, and even now very small compared with that made available for R&D on thermal nuclear reactors. They have also suffered from inadequate and late funding for subsequent full-scale prototype and trials programmes.

Energy conservation

Despite numerous government investigations[21-25] into the savings which could be made in the energy needed to heat buildings by insulation, the recovery of waste heat from industrial processes, flue-gases etc., improvements in the efficiency of both domestic appliances and industrial machinery, progress in putting their analyses into effect has been remarkably limited. The Department of Energy concluded that 'the large potential for energy conservation places high priority on R, D & D . . .'.[26] The Department's expenditure on energy conservation R, D & D for 1980-81 was, in fact, only £229,000.[27]

Detailed analyses of conservation programmes have been made by the Building Research Establishment,[28] Lovins,[29] Leach *et al.*[30] and others, and show that even without the use of more advanced techniques such as heat pumps and sophisticated control systems, total energy savings by the year 2000 of 20-25% could be achieved; in nearly all cases the costs are small, with payback times of 3 years or less. One-half of Britain's housing could, for example, have loft insulation for less than the price of a single PWR — and would be eight times more cost effective,[3] a point considered by the Select Committee on Energy.[20] A similar factor (six) was found in a programme carried out by the Tennessee Valley Authority.[31] Insulation requires negligible maintenance and houses last longer than power-stations, and so the total savings are considerable.

The saving in electricity consumption could likewise be about 20%, by correct rating of induction motors and switching off plant between operations in industry, by better insulation for domestic ovens and refrigerators etc.[30] In these and other cases more sophisticated control systems could increase the figure. The reduction in the use of electricity for low-grade heating would provide further savings.

District heating

District Heating (DH) based on a network of concentric hot-water pipes has many advantages over existing systems in urban areas for supplying space and hot-water heating for domestic and other buildings and to provide low-grade heat for industry — which make up over half the total energy demand. For the consumer it is cheaper than electricity and just as convenient. The fuel is burnt in large central boilers at higher efficiency and can use fluidised-bed or other pollutant-removal systems not feasible in domestic systems, and low-grade fuels may be used. The transmission losses are typically below 10%, so that in comparison with off-peak electricity, some 3½ times the useful energy is provided by each tonne of coal mined.

2 A solar-powered water pump with storage tanks in operation in a refugee camp in N.W. Somalia. The pump is made by Solar Electrical International (SEI)
[Photo: courtesy OXFAM]

The system is two-way, and besides providing low-grade heat to industry, can accept waste heat from flue-gases and various processes, so that an input is readily available from industry as well as the waste heat from power stations (CHP). Unlike electricity, the central storage of heat to provide peak loads is straightforward.

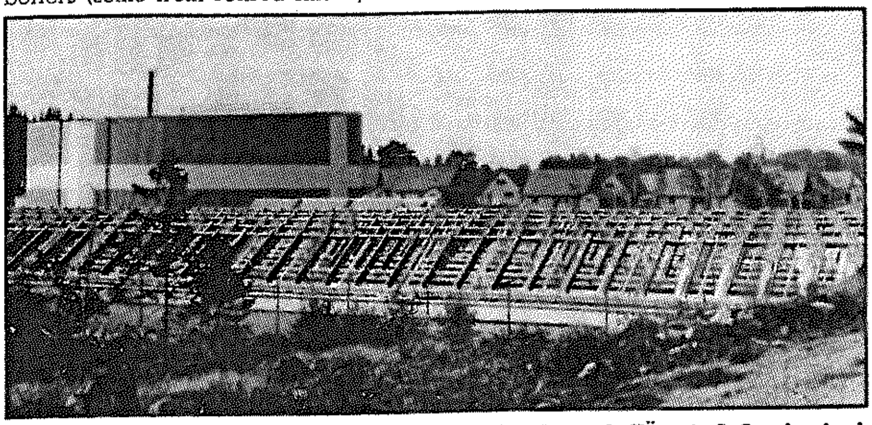
The use of CHP turns the 'merit order' of generating stations upside down; our large remote 'efficient' (34-35%) stations have to be compared with the small stations with a total fuel efficiency of 75-80%.

A number of small private schemes have been built as well as the larger systems at Peterborough and Nottingham (which burn mainly refuse), and the Hereford industrial system installed by the Midlands Electricity Board. Yet the Department of Energy has given little priority to such schemes — and announced a programme in 1980 to 'test the feasibility' and to try and locate a suitable site for a demonstration scheme. Their reports[32] and that of the UKAEA[33] concentrate on many difficulties and limitations ('25% of the population might ultimately be served by DH' . . . but 'this is an "ambitious proposal" i.e. it represents an upper bound rather than a realistic target').

Presumably the Department of Energy has investigated the use of DH in Denmark (where there seems to have been no difficulty in locating the 300 sites in use today), in Sweden (where it is planned to increase the proportion of the present heating load of 20% to 50% by 1990, subsequently phasing out nuclear power[34]), or the 800 systems operating in the USSR (supplying 40% of the heating load) besides other countries where DH schemes have been in use for years.

Denmark is particularly relevant, having no nuclear, no hydroelectric power, no coal and a climate very similar to our own. DH systems now supply 30% of the housing sector's needs (built up from 15% in 1963); one-third of this is from CHP, the rest mostly from oil-burning boilers (some from retired small power stations). Care was taken in the siting of large baseload stations so that their waste heat could be used. Although the capital cost per house is about twice that of a domestic oil/gas boiler, the overall heating cost (interest + fuel) to the consumer is about one-third that of an individual domestic boiler.[35] If we were to copy the Odense coal-fired system in the UK today it would produce heat at one-quarter the cost of electricity.

By 1995 it is planned that 35-45% of all building heating will be by DH (using heat from CHP and burning refuse, straw, coal and oil); 25% is to be from individual gas boilers (intermediate population densities) and the remainder from renewable sources and coal-fired electricity (remote areas).[36] A similar geographical distribution is planned in Sweden.[37]



3 This 1300 m² array of solar heat collectors at Ingelstad outside Växjö in S. Sweden feeds a seasonal water store used to provide heating for 52 houses
[Photo: courtesy Energy research & development commission, Stockholm, Sweden]

Renewable energy sources

Many authors have discussed the application of solar-heat collectors, solar photovoltaic cells, wind, wave and tidal power. The intermittency of such sources means that storage is often necessary (sensible or latent heat, heat of combination); since the heat stored is proportional to the volume, and the losses to the surface area, large stores are more efficient. In the case of DH, the long-term storage of heat becomes possible, not only to remove the fluctuations of the source on a time scale of days, but on an interseasonal scale to use summer solar heat. Two such schemes (50-60 houses) have been built in Sweden and a much larger system has been approved.[38,3]

Funding for R&D for renewable sources was virtually nonexistent until 1977, and even now the Department of Energy funds for *all* renewable sources for 1980-81 were £9 million.[27]

As a result, the UK has fallen behind other countries in most developments: solar water-heating is used in 2 million Japanese houses; an array of three 2·5 MW wind-turbines is operating in the USA, with improved designs under construction there and in Sweden and Canada. An 80 MW installation should be operating in Hawaii by 1984, and a 350 MW system near San Francisco has been started. Plant has been designed (e.g. USA, France and Brazil) for the digestion of forestry and farm wastes or specially grown crops to provide transport fuels (France plans to provide 25-50% in this way over the next 10 years). Sites for 'mini-hydroelectric' schemes (a few kW to 5 MW) capable of providing 60 GW of competitive electricity have been located in the USA.

An interesting table showing the (US) costs of *available* systems of conservation and alternative sources[39] shows that all are cheaper (some considerably so) than centrally-generated electricity and future synthetic transport fuels (coal/shale).

All of these developments would appear to have application in the UK; many would have excellent export prospects.

Other arguments for nuclear power

It has repeatedly been claimed that nuclear power is cheaper than that from coal stations, and that the latter should therefore be replaced by nuclear ones. The true cost of nuclear electricity has been examined by many committees and authors[5,40-42] who conclude that it has never been, and never will be, as cheap as that from coal-fired stations. These arguments — largely based on applying current cost-accounting methods instead of those used until this year by the CEGB — cannot include the unknown costs of disposing of radioactive waste nor of decommissioning retired nuclear reactors.

Since there seems little possibility that FBRs[14] or fusion could provide cheaper electricity than thermal reactors (Dr. Walter Marshall feels that the chances of fusion becoming economical are so slight that he gives them 'zero weight'[43]), the case for replacing coal stations for the rather small proportion of electricity needed in a viable long-term energy programme seems to vanish. We should also note the collapse of the US nuclear industry, with only two (uncancelled) orders for reactors since 1974 and with 45 postponed and 25 cancelled outright during 1977-8.[3] Why does the Government think that the UK industry can do better?

The Third World

It has been argued that only nuclear power can provide the energy needed by the Third World. That the poorest countries should invest any overseas credit they may have in the most expensive source of energy yet devised does not make sense, especially when it would impose a technological imperialism for a generation or more.

But there are even stronger arguments: over one-third of the world's population has no safe drinking water, while 15 million people — mostly children — die of hunger every year. The over-riding needs relate to the nonurban areas and here the provision of borehole pumps or desalination plant for drinking-water and irrigation, and the replacement of firewood for cooking are the first priorities. The gathering of wood is a major problem in many areas, but in the longer term is leading to the destruction of forests and the consequent growth of deserts.

The energy/km² needed is often too low for economic operation of any centralised system, and small-scale distributed energy sources are imperative.[44-46] Some 30 experimental water-pumping systems (which, of course, have inherent storage) using conventional electrical pumps driven by photovoltaic cells have been installed by Oxfam in NW Somalia. The cost of such cells has fallen by a factor of ten since 1976 and this decrease is expected to continue with new types of cell (e.g. amorphous silicon) and the introduction of quantity production techniques.[47,48] The 1980 US Department of Energy goals envisaged competitiveness with diesel generation by 1982 and with all forms of generation by 1990.[47] Such cells provide electricity on any scale required.

In other areas wind pumps (which allowed the development of much of the N. American continent — where some 10 GW were built) may be more appropriate; in others, microhydroelectric systems (60 000 installations, of typically 50 kW, were already in operation in rural China by 1975). The development of small-scale methane digesters to provide cooking and lighting (some 5 million were built in rural China in 6 years) can replace firewood and provide much-needed fertiliser.

But perhaps the most important objection to the spread of nuclear power is its inevitable relationship to weapons proliferation. It is often argued that there are other routes to nuclear weapons, which is certainly true, although complicated and clandestine operations are needed. The provision of 'know-how', equipment and fissile material for building 'research' or 'power' reactors has provided, and will continue to provide, the only politically-respectable route, and one which no method of inspection can control.[49,50]

Conclusions

The Government's proposed nuclear programme would only make an insignificant contribution to the energy which will be lost by oil/gas depletion, and it is extremely urgent to put in hand other programmes which can make an effective contribution.

The immediate attention to saving energy now wasted, the installation of district heating schemes in urban areas and a modest introduction of renewable energy sources could, by the end of the century replace most of the nontransport uses of oil, without increasing our present coal production. Many waste-saving techniques are simple and there seems no reason why, for example, DH schemes should not be introduced at a *per capita* rate equivalent to those of Scandinavia. The much-discussed administrative difficulties of these programmes have been solved in other countries and, in any case, seem to present problems no worse than our very successful programme of conversion to North-Sea gas.

The obsession with nuclear-based electricity as the main source of our future energy supplies has led to inadequate development of these alternative programmes, but we must now take advantage of progress in other countries for their further development and in the progressive expansion of renewable sources and other more sophisticated developments for the long-term future. The programmes discussed are all cheaper than a nuclear-electricity solution, some considerably so.

If nuclear power were to be abandoned, it would be seen by some — especially those who have given their working lives to its development — as a retrograde step. But this is not a new problem in engineering; the extremely challenging aerodynamic, structural, control and instrumentation problems, which were solved in the development of Concorde, have produced a magnificent piece of engineering, but one which appears to have no future in the present world.

We must put our energies into solving the difficult problems, in many disciplines, which are involved in renewable sources — on which both the developed and the developing countries must eventually depend.

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Sir Martin Ryle, F.R.S., is a Fellow of Trinity College, Cambridge, Professor of Radio Astronomy and Director of the Mullard Radio Astronomy Observatory, University of Cambridge, Department of Physics, Cavendish Laboratories, Madingley Road, Cambridge CB3 DHE, England. In 1974 he was joint winner of the Nobel Prize for Physics. He is an IEE Member

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Sir Martin Ryle F.R.S., F.Eng.

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Sir Martin Ryle F.R.S., F.Eng. is Professor of Radio Astronomy in the University of Cambridge. He received a Nobel Prize for Physics in 1974.

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