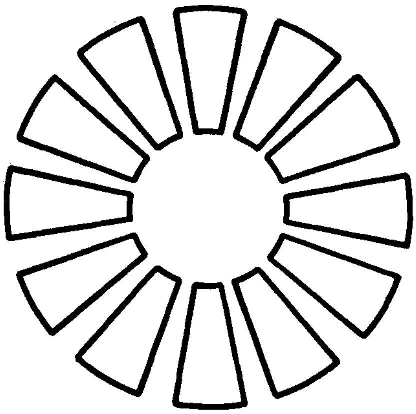

An
Alternative Energy
Strategy
for the
United Kingdom

An Alternative Energy Strategy for the United Kingdom

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PREFACE

by the Astronomer Royal

Professor Sir Martin Ryle FRS, MIEE, CEng.

We have become accustomed to believing that our standard of living and full employment both depend on an ever-increasing consumption of energy - to heat our homes, to provide more transport and especially to produce increasing quantities of manufactured articles which consume both energy and other mineral resources some of which have limited reserves. If we continue in this belief, the energy shortage initiated by the exhaustion of the world's oil reserves will, by the end of the century, forcibly curtail the present trends in the worst crisis civilization has yet experienced. The time-scale is so short that it is not clear that any viable nuclear programme can avoid the energy problem, while providing no solution to the exhaustion of other resources.

The authors of this report put forward a possible alternative solution to our immediate problems which at the same time points the way for the longer-term future of both developed and developing countries. It is based on the supposition that we are eventually likely to have to live on the large and continuing input of energy provided by the Sun, and it shows that by urgent action now - both in the development of the new technologies needed to abstract this energy, and by better use of the energy we have, by the manufacturing of goods designed to last, by better house insulation and the use of much "waste" heat, there is no need for the large-scale development of the "plutonium economy".

This country has the technological skills and production capacity to play a major part in the provision, for both home and export markets, of viable wind, wave and tidal energy systems, solar panels and cells, hydrogen and other storage systems, heat pumps and methane producers, and if we develop them now, we could not only solve our own energy and economic problems, but contribute to a safer future for the world.

Martin Ryle

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1. INTRODUCTION

Since the beginning of the Industrial Revolution in the eighteenth century the rate of consumption of energy by the inhabitants of the United Kingdom has increased dramatically. Almost all of the energy has been obtained from the burning of so-called primary fuels (coal, oil etc). Since the Second World War the total consumption of primary fuels has been increasing at about 1.9% p.a., a rate of growth which involves a doubling of consumption every 37 years. During this period the consumption of coal has declined, the use of oil and natural gas has vastly increased and nuclear energy has made a small but growing contribution. The only "renewable" (i.e. non-fossil-fuel) energy source of which significant use has been made is hydro-electric power generation.

The growth of energy consumption has been accompanied by an increasingly acute realisation (most evident since 1973) that the resources of fuel available to the UK are limited. It is expected that the rate of extraction of oil and gas from the North Sea will reach its peak during the 1980s and then decline. The resources of reasonably accessible coal, though large, are not inexhaustible.

The conventional way of drawing up an energy policy, having regard to the historic trends in energy use and the limitations of traditional resources, is to predict the future "demand" for energy by extrapolation from past consumption, making some allowance for savings that might be achieved through conservation measures, and then to plan to satisfy that demand using a combination of the available energy sources. (It is noteworthy that the equivalent policy of building new roads in the hope of satisfying the predicted demands of road traffic has not solved the problems of congestion: the supply appears to stimulate the demand.) In this policy-making procedure the energy demand figure is sacrosanct and the fact that traditional fuel resources are limited only has the effect of requiring that new sources of energy be found and exploited in increasing amounts. Such a procedure underlies the predictions made by the Department of Energy and shown in Figure 1 concerning the growth of the total primary energy use in the UK in the next 50 years. The width of the band within which the energy total is expected to lie reflects the inevitable uncertainty of such long-term forecasting. The Department anticipates that in this period the North Sea oil and gas stocks will be rapidly exhausted, coal consumption will rise, possibly by as much as two thirds, "alternative" energy sources - the sun, the wind, the waves, geothermal and biological systems - will make a modest contribution, and the rest of the increasing demand will be met by using nuclear energy at a steeply increasing rate.

A commitment to a large-scale nuclear programme involves a number of difficulties, some well known and others which have scarcely been faced. The so-called "burner" reactors make inefficient use of their uranium fuel (of which the UK has virtually no currently exploitable resources). The so-called "breeder" reactors have the attraction of being much

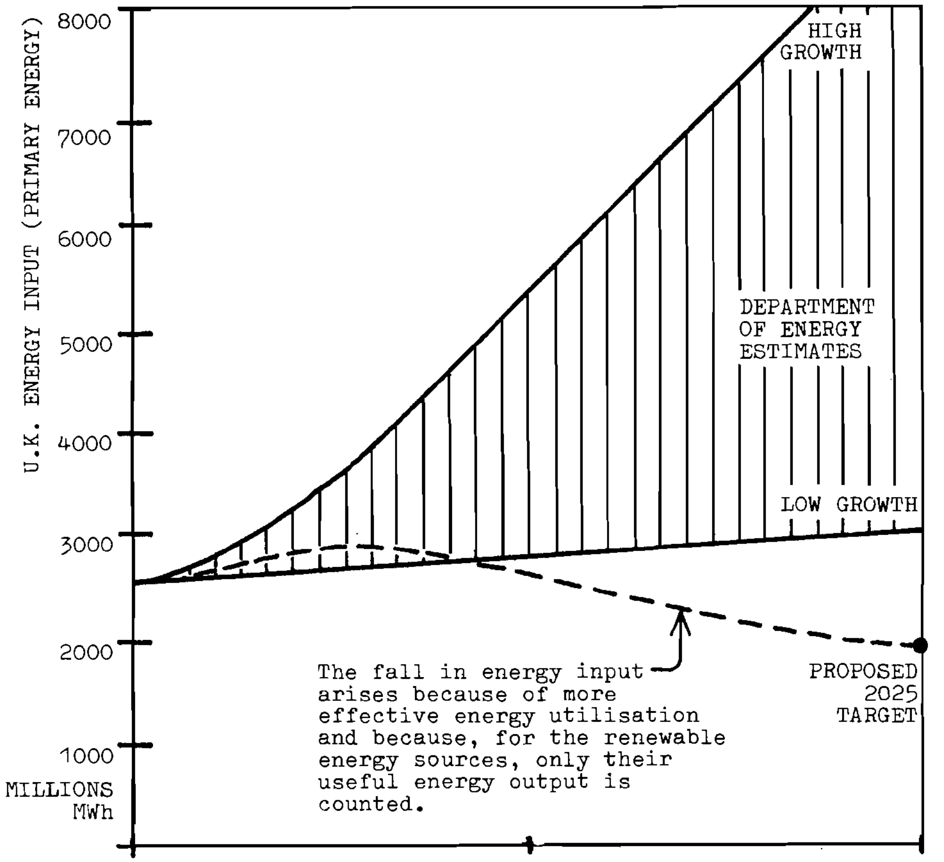

FIGURE 1

more efficient in their use of fuel but they involve the storage, handling and transportation of substantial quantities of plutonium, which is highly toxic and of military significance. Both types of reactor produce waste products which remain dangerous for very long periods of time. The Royal Commission on Environmental Pollution in its Sixth Report has drawn attention to the hazards of a large-scale nuclear power programme based on breeder reactors, mentioning the risks associated with accidents within reactors, the political risks involved in the so-called "plutonium economy" and the problems of the safe disposal of radioactive waste. On this last point the report recommends that there should be no commitment to such a programme until it has been demonstrated beyond reasonable doubt that a method exists to ensure the safe containment of long-lived, highly radioactive waste for the indefinite future.

Further problems of a largely nuclear energy policy arise from the fact that the energy from both burner and breeder reactors has to be extracted in large power stations, in which heat from the reactors is used to generate electricity. The efficiency of conversion from heat to electricity is at present below 30% and over the next few decades is unlikely to be much greater than one third. This means that for every one unit of electrical energy supplied to the national grid three units of nuclear heat energy are required and two units of low temperature heat energy have to be disposed of. Since nuclear power stations will probably continue to be sited away from large centres of population, it is unlikely that much of this heat will be able to contribute to the energy needs of the country by meeting domestic, commercial and industrial heating requirements. (This problem of waste heat utilisation also affects coal-fired power stations of the large sizes recently built but whereas coal stations can without great penalty be built in smaller sizes and sited close to towns nuclear stations cannot.) It follows that in a predominantly nuclear energy regime almost all of the heating load, except that which is borne by coal,would have to be borne by electricity, since oil and gas would by then be too valuable to burn. This extensive use of electricity generated in remote nuclear power stations to meet heating requirements has serious consequences. Firstly, it involves committing resources of capital, materials, land (and energy) to the building of additional power stations, with their great sophistication, merely to supply heat to the consumer. Secondly, it requires the capacity of the national grid to be vastly increased. Thirdly, it calls for large-scale energy storage installations to smooth out the highly intermittent heating load. Fourthly, it involves greatly increased "thermal pollution" due to the rejection into the environment at the power stations of vast quantities of waste heat, amounting to about twice the heating load that is borne electrically. The complexity of such a practice is matched only by its profligacy.

It is suggested that nuclear fusion - the process that creates the sun's energy - could ultimately be used in a controlled way to meet mankind's energy needs for the indefinite future. Even if a safe and practical system can be made to work, it is very unlikely that nuclear fusion will make a significant contribution within the next 50 years.

In an alternative approach to the formulation of an energy policy one first recognises that the earth's energy "capital" - the fuel reserves - is finite, and also that the energy "income" to the earth - the perpetual flow of energy emanating from the sun, which manifests itself on earth as sunshine, wind, wave, tidal and biological energy - arrives at a large but finite rate. The capital, once used (in the sense that its energy has been degraded to useless low temperature heat energy), cannot be re-used, and its use (for whatever purpose) has the possibly undesirable long-term effect of raising the temperature of the earth's surface. The energy income is inexhaustible, diffuse, non-polluting and seldom dangerous. It is also abundant. The present annual consumption of energy in the UK is equal to the solar energy which falls each year on a 25 mile square area of land. A balance exists: the earth receives energy from the sun and radiates energy into space at a virtually equal rate. In harvesting for our own purposes the mechanical energy of wind and waves or the heat energy of sunshine we merely redirect the solar energy in its natural process of decline from mechanical energy to heat energy, and from hot to cold. We do not disturb the balance. Energy income is variously described as "ambient" energy, "renewable" energy, "alternative" energy and "unconventional" energy.

Granted that the reserves and income of energy are both limited, it is clear that the historic pattern of exponential (or even faster) growth of consumption of energy cannot be sustained in the long term. Ultimately, when the bulk of the reserves has been consumed or when they are more valuable as chemical feedstock than as fuels or when further thermal pollution is unacceptable, mankind will have to live on the energy income which he today describes as unconventional. The level of energy consumption by society will then be determined by the effort that is devoted to diverting the incoming energy to human purposes.

With these long-term constraints in mind, one next has to decide on a reasonable target for annual energy consumption at a given date, say the year 2025. The target is based firstly on an estimate of how much income energy could reasonably be harvested, having regard not only to economic and environmental factors but also to the amount of energy required to build the equipment, secondly on a decision as to the rate at which the remaining fuel reserves (both fossil and nuclear) can responsibly be consumed, and thirdly on an estimate of the minimum energy necessary to sustain the life of the population at an agreed "quality", in terms of such factors as nutrition, health, shelter, comfort, work, education, mobility, leisure, culture, independence, safety, privacy and freedom. Reaching agreement on an energy target is very different from the current practice of making demand predictions based on past trends - and is much more difficult to achieve. Figure 1 shows a possible target for 2025.

Having established the energy target, one has to decide how and when steps should be taken to force the rate of energy consumption to break from its historic growth curve and to begin to evolve towards the target figure, for example in the way indicated by the broken line in Figure 1. Obviously, for a given target, the sooner such measures are taken the less traumatic the transition. Gradually, the conventional belief that happiness is proportional to energy consumption would need to be displaced. Certain steps, like concerted energy conservation in homes, offices and factories, possibly encouraged by financial incentives, can bring almost immediate savings of energy. Other measures to discourage the growth of inessential but energy-consuming practices like over-packaging, advertising and private motoring take longer to have an effect. One also has to plan the gradual introduction of income energy - solar, wind, wave and tidal energy - as the use of fossil fuels is gradually reduced.

This report presents the outline of an alternative energy strategy for the UK, formulated along the lines described above, for the period upto the year 2025. The energy consumption target is the figure which results from providing the consumer in 2025 with approximately as much "end-use" or "useful" energy as he used in 1975. First, each of the various income energy sources is discussed and an estimate is made of the annual energy contribution which each could realistically be expected to make in the year 2025. The role of heat pumps is described. The rate of coal consumption assumed for 2025 is similar to that envisaged by the Department of Energy and thought to be reasonable by the National Coal Board. The possible contributions from geothermal energy (which is essentially a capital resource) and from solar electric cells are discussed. Energy conservation methods are assessed. The important process of matching a diversity of energy loads, covering a spectrum from hot water to transport, to a range of very different energy sources, from low temperature heat energy to mechanical and electrical energy, is illustrated. Certain economic and employment implications of the strategy are considered and, finally, conclusions are drawn.

In this report rates of energy flow, or power, whether electrical, mechanical or thermal, are expressed in watts (W), kilowatts (kW) or megawatts (MW). Quantities of energy are expressed in millions of megawatt hours, written million MWh.*

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* 1 million MWh is alternatively known as 1 terawatt hour, TWh. 1 million tons of coal equivalent, mtce, equals 7.45 million MWh.

2. ENERGY SOURCES

2.1 Solar Energy

Solar energy is perhaps the most attractive alternative energy source available in the United Kingdom. Until quite recently it had been thought that our relatively high latitude was an insurmountable handicap but in the summer months from May through to September the average daily solar radiation experienced in the UK is about as good as anywhere else in the world. Every year the total amount of solar radiation reaching the earth's surface is about 1000 million million MWh. Some idea of the order of magnitude can be obtained by realising that this is some fifty times greater than our present world proven fossil fuel reserves and some ten thousand times greater than the total annual world energy consumption.

There are several factors which must be considered in any application in the UK. Firstly, the maximum intensity of solar radiation is no more than 1 kW per square metre. Averaged over a whole year the intens is about 105 W per square metre, a value which is about half that of the best areas in the world. Secondly, in any application where continuous operation is essential some form of storage must be provided as the level of radiation is usually too low for conversion outside the four hours on either side of the solar noon. Thirdly, only half of the radiation consists of direct sunlight, and this means that focussing devices will not be very effective. Finally, there is the very considerable variation between summer and winter conditions.

The most immediate applications of solar energy are water heating and space heating. Although the figures given below are for 1971, there is no reason to believe that the pattern has altered significantly since then. The pattern of energy consumption indicated is confirmed by three recent publications from The Building Research Establishment, The Department of Energy and the UK Section of the International Solar Energy Society. Overall conclusions reached by the BRE, based on the UK Energy Statistics for 1972/3, were that about 40% to 50% of the national primary energy consumption is used in building services and over half this energy is consumed in the domestic sector.

Annual consumptions of useful energy in buildings (millions MWh)

	Domestic	Commercial and public	Total
Space heating	148	105	253
Water heating	57	34	91
Totals	205	139	344

Solar collectors are already commercially available and an area of 6 square metres can provide about 50% of the domestic water heating energy for a typical household. On the assumptions that by 2025 the water heating load is similar to its present value, that all new housing and commercial and public buildings will have solar water heating and that the remaining housing stock and all other buildings will have been completely "retrofitted", the solar energy contribution would be 45 million MWh. This estimate is conservative since more efficient collectors will be developed to make better use of our lower winter radiation levels.

The key to successful space heating applications will be the development of appropriate heat storage systems. There is already evidence both from the USA and Germany that successful heat-of-fusion storage systems have been developed. Even without these systems, the combination of good insulation and conventional water or rock storage will enable up to 80% of the total space heating demand of a house to be met with a solar collector of about 30% of the floor area. Buildings have been designed which can provide all their space heat from solar energy, even in the UK climate, and it is reasonable to expect that such buildings will become quite common over the next 50 years. The economies of long-term heat storage become more attractive when large heat stores can be shared between a number of dwellings. It is difficult to predict how rapidly these techniques could be introduced but if only a quarter of the domestic and commercial buildings are 80% solar heated, the energy contribution would be 51 million MWh. An additonal 32 million MWh could be gained if a further quarter of the building stock were fitted with partial (say 50%) solar space heating.

A detailed breakdown of industrial energy uses is not available, but a significant fraction of the energy requirement is for low temperature heat for space heating, water heating for personnel, and low temperature processes. It is estimated that together these require 180 million MWh per year of useful energy, towards which solar energy could contribute about 70 million MWh per year. Several industrial installations with collector areas over 100 square metres are already operating successfully in the UK.

These calculations suggest that, taken together, solar installations for water, space and process heating could provide 198 million MWh of useful energy in 2025. This figure is consistent with the findings of other groups. According to the UK Section of the International Solar Energy Society, in the year 2020 12% of the 1972 UK primary energy could be provided by the use of solar water and space heating in the domestic, industrial and commercial sectors. The Department of Energy estimates that in the year 2030 solar water and space heating in the domestic sector alone could save 170 million MWh of primary energy.

The present cost of commercially available solar panels ranges from £50 to £100 per square metre. These figures and professional installation costs are artificially high because the industry in the UK is in an early state of development. Estimates of the likely cost of solar energy, allowing for technical development and economies of scale, range from £300 per kilowatt of average output, for low temperature applications (e.g. swimming pools, and cold water pre-heating) to £1500 per average kilowatt for high temperature water applications. The present cost of nuclear power stations is about £800 per installed kilowatt, which corresponds to a figure of £1330 per average kilowatt. It is estimated that a solar heating system can recover a quantity of energy equal to that invested in its manufacture in about two years.

2.2 Wind Energy

The power output from a windmill is proportional to the cube of the wind speed, and for low cost energy production windmills must consequently be located in areas of high mean wind speed. On land this indicates siting windmills in coastal areas. The highest mean wind speeds are found on hill top sites. The Electrical Research Association, in the 1950s, surveyed and selected approximately 1500 suitable hill top sites, having mean wind speeds at the summit of about 9 m/s (20 mph). On average three windmills, each with a rated power output of about 1 MW, could be located on each summit, giving a potential wind power capacity of approximately 5000 MW. The energy output from such a windmill system would total approximately 18 million MWh per year, which is equivalent to about 8% of the present electricity consumption in the UK. Many of the hill top locations suitable for large windmills are in areas of great natural beauty and there may consequently be environmental objections to siting windmills in such areas. Other workers have proposed the use, on less optimum sites, of larger numbers of windmills ranging from 1 MW down to 30 kW, which would be about the size of a traditional corn-grinding windmill. This approach would at first seem to have a considerable economic disadvantage, requiring more windmill structure per megawatt hour generated, but it is conceivable that other factors such as mass production economies, reduced site costs and less visual impact could tip the balance in its favour. It is important to recognise that the environmental impact of windmills is confined to their visual effect: they leave no legacy of waste and pollution. With appropriate designs the visual impact of modern windmills need be no more severe than that of their traditional predecessors.

Windmills may also be deployed offshore, where their visual impact would be minimal. Britain is surrounded by extensive areas of windy, shallow water, and windmills located in such areas would provide an energy potential well in excess of that obtainable from windmills on land. The southern North Sea is a particularly good location, both because it is shallow and windy, and because windmills in this area would be close to the main centres of energy demand in the Midlands and the South of England. Mean wind speeds in the southern North Sea are comparable with mean wind speeds on hill top locations, and a windmill having a diameter of about 70 metres (230 ft) would give a rated output power of about 2.5 MW and an annual average power of 1 MW. The large open areas available would allow such windmills to be deployed in clusters of about 400 spaced half a kilometre apart. Each cluster would have a rated output power of 1000 MW - comparable with a large power station on land - and would occupy an area of only

10 km by 10 km. Windmill clusters would be located some 10 to 50 km offshore, so they would be either inconspicuous or invisible from the coast. Within each cluster the electricity outputs from individual windmills would be connected together, and the total output of upto 1000 MW brought to the shore by submarine cable. In the shallow, windy waters around our coast, there is room for at least twenty-five such windmill clusters: these could provide 40% of our present electricity consumption and save either 39 million tons of coal or 24 million tons of oil every year. The combination of land-based windmills with windmills offshore could therefore provide approximately 106 million MWh of electricity per year, equivalent to 48% of our present electricity consumption.

Since the wind does not always blow when we want power and sometimes provides more power than we can use, some form of energy storage is essential. This may be provided centrally or at the point of use, or some combination of both. The question of energy storage is discussed in Section 4.3.

Is the cost of energy from the wind competitive with that from existing sources? It has been estimated that offshore wind energy systems would cost approximately £440 per installed kilowatt with the result that they could provide electricity at about 1.2p per kWh; the costs would be rather less for on-land systems. Wind energy without storage could be used as a fuel saver, allowing the load on fuel-fired power stations to be reduced on windy days, and will be economic if the price of oil to the power station exceeds £44 per ton (this being the figure corresponding to 1.2p per kWh). The present world price of crude oil is about £52 per ton, though the residual oil used in power stations is somewhat cheaper. Given recent predictions, by the OECD and others, that the demand for oil will exceed supply by the mid 1980s, one can expect to see large increases in real money terms in the price of oil and other fossil fuels over the next decade. The economic arguments for using wind energy will consequently get progressively stronger. The energy invested in the construction of a wind energy system would be repaid within the first year of its operation.

Quite apart from their use in the UK, wind energy systems could fulfil a valuable role in meeting the energy needs of other industrialised nations and the developing world. The production of windmills, for use in the UK and for export, could also provide a productive outlet for Britain's underused industrial capacity.

There is at present no programme to develop large scale wind energy systems in the UK.

2.3 Wave Energy

Waves are potted wind energy. Winds out in the Atlantic spend some of their energy creating waves, which then deliver that energy to the western coastline of the British Isles. The energy crossing a 1700 mile long contour, ten miles from the shore of Great Britain, is about 500 million MWh in a year, which is more than twice the energy produced by all the Electricity Boards in the UK in 1974. The North and West of Scotland receive about one million megawatt hours per mile of coast, which reduces to about 0.3 million megawatt hours to the South and West of England. It is not possible to collect all this energy, but could some of it be collected? Could it be converted into electricity? What would be the cost of that conversion? What would it mean to the UK to develop this source of energy?

As part of its assessment of alternative sources of energy for the UK, the Department of Energy is spending £2½ million in an attempt to find answers to these questions. Four different ways of tapping the energy are under investigation, with a separate team concentrating on developing each method, and with other teams looking at the general problems associated with any wave energy machine. By autumn 1978 the Department of Energy hopes to know what each approach means in detailed engineering terms; the best shape of device, how it would be made and who could make it and where; the best way to deliver the power to a generator; the best way to moor the devices safely, and how to transmit the power to shore. Details will be available on the regularity and reliability of wave energy so that the need for standby plant or energy storage can be assessed, and costs will be analysed, together with estimates of the time needed to develop each device to give useful quantities of electricity.

The first stage of these investigations has shown that the energy can be extracted from the waves and converted into mechanical form. Three of the four methods have already demonstrated their ability to extract over half the energy in a wide range of sea states, in laboratory tests in tanks. The details of converting that energy to electricity are not finalised, but certainly efficiencies of over 50% can be achieved over a wide range of conditions. Obviously there are detailed problems to be solved, but the probability of success is high. Machines can be built which will deliver at least 25% of the wave energy that comes at them as useful electrical energy.

Assessing the cost of such systems is more problematic. In engineering costs depend on details not on broad ideas, and the cost implications of each approach to extracting wave energy from the sea remain to be established. Capital costs of £400 to £800 per kW have been suggested by the Central Electricity Generating Board as very rough estimates: these are low enough to make further work worthwhile.

If the engineering problems are solved and the price is reasonable, how much energy might the UK expect to get from the waves? With wave energy absorbers reasonably spread apart at sea, (covering 40% of the wave front, say), the above estimates would suggest an output of one million MWh per year from 10 miles of sea. More optimistic estimates (more efficient devices, more closely spaced), would double this. Shipping and other requirements reduce the usable coastline to between 500 and 1000 miles. A practical expectation might be 50 million MWh per year from a 500 mile string of collectors, situated to the West and North of Scotland, with a further 6 million MWh per year from 200 miles West and South of Cornwall. Technical development could improve on these figures. 40 million MWh per year could be available by the end of the century.

Wave energy by itself is intermittent. There are days when there are no waves at all. However, the Electricity Boards have thermal power stations to spare which could provide a back-up supply. What is most attractive is that wave energy is highest in the winter months when demand is at its highest. The power "supply" curve follows the "demand" curve, so that the back-up or storage requirements are kept to a minimum. Additionally, the areas at which wave energy is available are just those areas which lack generating capacity. Northern Scotland imports two thirds of its electricity from the South. Wave power could make Northern Scotland, Northern Ireland and Devon and Cornwall net energy exporters.

Unlike the rapid development of North Sea oil, the development of wavepower would not overload these remoter areas with a workforce imported for a few years, only to depart once the energy was removed. The development phase is necessarily slower and less intensive, the continuing work in terms of maintenance of equipment is a much larger part of the whole: the employment, like the source of energy, is there forever. With a carefully thought out development programme, wave energy could be a key industry, providing the power and the cash flow on which viable regional development policies could be based.

The development of wave energy offers hope to sagging regional economies: it offers hope to sagging industries as well. The major components of all wave energy devices have much in common with ships and the large concrete structures now being produced for North Sea oil rigs. The rig yards and the shipyards have spare capacity and empty order books. Similarly the power generation equipment calls on the under-employed skills of Britain's heavy engineering factories. There are also detailed problems in design, optimisation, fatigue, corrosion, control, and a host of other areas which UK research establishments are well qualified to tackle.

Britain now has idle capacity which could be producing wave energy devices - and every country in the world with a coastline is a potential export market.

2.4 Tidal Energy

Tidal power systems, like windmills, have a long history dating back to mediaeval times. Today large tidal energy schemes are in existence and operating successfully, for example the 240 MW French scheme at La Rance.

Most systems consist of a barrage across a natural estuary and a row of low-head water turbines mounted in ducts passing through the barrage. As the tide rises and falls the water on one side of the barrage rises above that on the other providing the pressure head necessary to drive the turbines. In simple systems the power produced varies cyclically with tidal flow or occurs in several "blocks" during the day. By splitting the estuary into two basins, control can be exercised over when, during the day, power is produced and, if necessary, a continuous power output can be achieved. However a more economic solution may be to design the system for maximum energy production, regardless of timing and to make use of existing energy storage facilities elsewhere.

Recent technical advances in turbine design and barrage construction techniques should enable new schemes to be constructed at a cost which would make the unit energy cost competitive with that from nuclear power. Studies have been carried out on suitable sites around the UK and it is estimated that the most promising site, the Bristol Channel, could provide about 13 million MWh per year of electricity. The initial investment required is high, but such a system with its long life, small environmental impact and zero fuel cost would be a valuable asset in years to come.

2.5 Hydro-electricity

In a hydro-electric installation, rainwater is collected in a reservoir at a high level and flows under gravity to a power station at a lower level, where it passes through turbines which drive electric generators. Such a system has the attraction of combining an intermittent but inexhaustible energy source - the climatic process of water evaporation and rainfall - with energy storage, so that electricity can be generated when it is required, regardless of short-term changes in the weather.

The present installed power capability of hydro-electric installations in the UK is about 1300 MW, delivering approximately 3 million MWh per year of electricity into the national grid.

The North of Scotland and Wales are the obvious areas in which further hydro-electric installations could be built. The price that has to be paid, in addition to the capital cost, is the damage to the countryside caused by building dams, flooding valleys and diverting streams from their natural courses. The actual generating stations and the power cables can be put underground to minimise the environmental impact.
It has been suggested that suitable sites exist in the North of Scotland for the building, at reasonably economic prices, of hydro-electric stations capable of generating a further 1000 MW of electrical power, that is, approximately doubling the present power capacity in that region. This indicates that by the year 2025 the total hydro-electric power capacity in the UK could be about 2500 MW, generating about 6 million MWh per year of electricity.

A significant further contribution could be made by the installation of small water turbines on some of the large number of minor rivers and streams in the UK. Such development is more appropriately carried out by local authorities and individuals than by the national generating boards. Some changes in the existing legislation on water use would be necessary to encourage this unobtrusive means of energy production.

2.6 Bio-fuels

Photosynthesis supplies practically all our food, fuel and fibre. These products are either derived from present day photosynthesis, or indirectly from fossil fuels which themselves are products of past photosynthesis and are not renewable. A better understanding of the mechanisms and possible uses of photosynthesis should enable us to realise its maximum potential in the future. One of the problems in persuading people to take this research more seriously is that its relative simplicity compared with other types of energy research and development leads people to under-estimate the potential of photosynthesis as an energy source.

Photosynthesis is the conversion of solar energy into fixed energy: carbon dioxide and water react in the presence of light to form organic material and oxygen. The organic material contains stored energy. Photosynthesis converts between 0.5% and 3% of the incident light energy to stored energy.

Until the eighteenth century almost all food, fuel and fibre were obtained from recent photosynthesis. However, the products of current photosynthesis are mainly used as food, as we now rely heavily on cheap oil, gas and coal for fuel and for artificial fibres. We should re-examine and, if possible, re-employ the previous systems; but, with today's increased population and standard of living we cannot revert to old technology, but must develop new means of utilising present day photosynthesis more efficiently. Solar-biological systems could contribute to energy supply through the production of stored energy in solid, liquid or gaseous form, for example the growing of fuel crops in "energy plantations" on non-arable or marginal agricultural land yielding wood or alcohol, and the generation of methane from organic materials.

An estimate of the possible contribution of photosynthesis to energy production by the year 2030 has been made by the Department of Energy assuming that the efficiency of photosynthesis can be 2%, that 20% of the land area of the UK is used and that conversion of organic matter to fuel is 50% efficient. The estimate is 444 million MWh per year. Even a more modest efficiency of photosynthesis of 1% and a 10% land utilisation would produce 111 million MWh. The Department has also estimated that UK organic wastes alone have an energy content of 111 million MWh.

2.7 Heat Pumps

A heat pump transfers heat energy from a substance at a low temperature to a substance at a higher temperature. The effect is utilised in the normal domestic refrigerator. The heat pump is relevant in a consideration of energy sources because it allows one to use the abundant stock of heat energy in the air, the ground, rivers and waste water, which is normally at too low a temperature to be useful directly. The energy delivered by heat pumps is most suited to space heating and water heating applications. The heat energy extracted from the environment is replaced naturally by solar radiation, and by heat lost from the building or from the heated water. A mechanical or electrical energy input is needed to drive the heat pump, but the heat energy delivered is usually about three times this input.

At present, the effect that heat pumps could have on primary energy consumption is significant but not large. This is because the electricity used to drive them is generated at low efficiency (less than 30%) from fuels such as oil and coal, and the overall efficiency (fuel to electricity to heat pump to heat) is only a little better than that for burning the fuel directly in a well designed appliance (fuel to heat). The heat pump does, however, offer a saving of a factor of two or three in primary energy consumption when it replaces electric resistance heating. The heat pump also enables heat energy roughly equivalent to the calorific value to be obtained from the low grade fuels which can only be burnt in power stations.

In the energy strategy considered in this report, a large fraction of the total electricity supplied would be generated by a combination of wind, wave, tidal and hydro-electric systems. By using part of this electricity in heat pumps to extract heat from the environment, its value for heating purposes can be substantially increased. For example, if 100 million MWh per year of electricity were allocated to heat pumps, 150 million MWh per year of otherwise useless ambient energy would be collected, and the total output of the heat pumps would be 250 million MWh per year - enough to provide about half our present demand for heating buildings.

Heat pump technology is well developed; many systems are in use in the USA and the number in this country is growing. Costs are not prohibitive now and could be reduced further by development of the UK heat pump industry. Widespread and early adoption of heat pumps with storage would give an immediate primary fuel saving and would be compatible with most energy strategies, which are all likely to involve increased transmission of electrical energy for heating purposes.

2.8 Other Energy Sources

Coal

The Department of Energy's booklet "Coal for the Future" states that it is probable that our technically recoverable reserves of coal amount to some 45,000 million tons - enough to support the current rate of production (126 million tons per year) for over 300 years - and geological evidence suggests that a substantial proportion of these reserves are of good quality. The National Coal Board is of the view that coal output in Britain could be raised to over 160 million tons per year by the end of the century. Such an output would have a calorific value of 1192 million MWh per year and could be maintained for about 250 years.

Solar-electric cells

Solar-electric cells convert light energy directly to electricity with an efficiency usually in the range from 4% to 10%. The present costs of commercially available solar cells are about £10 per peak watt (defined as one watt output at a light intensity of 1 kW per square metre). Even at this price there are applications which are economically viable in remote or very difficult sites. However, all the indications are that the very substantial cost reductions which are necessary to see the widespread use of solar cells in the UK can be achieved. In the United States it is predicted that the cost could be reduced to £0.25 per peak watt in the early 1980s. One of the most promising developments in the UK is at Patscentre International of Melbourn, Royston, where cadmium sulphide cells are being developed, using a chemical spraying technique on glass. No firm cost figures are available, but a reduction in price by a factor of at least ten compared with current figures is anticipated.

Until the problems of economic electricity storage can be solved, the likely impact of solar cells on the UK energy position is hard to predict. However, the introduction of solar cells integral with solar water heating panels could conceivably be economic in about 15 years, and much of the domestic, non-heating, electrical load could be satisfied in this way during the summer months.

Geothermal energy

Geothermal energy is the name given to energy obtained, usually in the form of hot water or steam, from naturally occurring hot regions below ground level. In certain areas of the world the geothermal sources are hot enough to be used for electricity generation, but more commonly the energy can be used only for relatively low temperature heating purposes.

The Department of Energy's recent report "Geothermal energy: the case for research in the United Kingdom" concludes that the prospects for geothermal development in the UK appear to be sufficiently favourable to warrant more detailed study in certain locations. The report points out that, since the rate at which heat would need to be extracted to make any scheme economically viable is very much greater than the rate at which the energy would be replenished by the natural upward flow of heat, geothermal energy should be regarded as a non-renewable, capital resource.

The report describes two types of geothermal source which might be tapped in the UK. Firstly, there are "hot rock" fields consisting of abnormally hot, but impermeable, rock, such as the granite spine of Cornwall. To extract energy from such a source it would be necessary to shatter the rock in order to make it permeable to water. Techniques for shattering are under development in the United States. The very tentative estimates made by the Department of Energy indicate that if the whole of the granite area of South West England were tapped it might yield a total output of heat, at temperatures of perhaps 200°C, of about 60,000 million MWh, equivalent to the energy content of about 60 years' output of coal at the present rate of mining in the UK. The Department's report suggests that if the heat energy in such a hot rock field were tapped over a period of 20 years at a rate of 200 to 300 MW per square kilometre, the cost of the energy at the site would be of the order of 0.2p per kilowatt hour, a cost which compares favourably with the present price of imported oil.

Secondly, there are areas where hot springs occur or where rain water may be able to penetrate sufficiently deeply to achieve useful temperatures. The Department of Energy's report suggests that such areas might conceivably allow the extraction of a further substantial quantity of energy, possibly at a lower unit cost than energy from hot rock fields.

If suitable geothermal sites are found reasonably near to towns, it appears that geothermal energy might be able to make a modest contribution to space heating requirements in the relatively near future.

3. ENERGY CONSERVATION

Many reports have been published on energy conservation which point to the considerable scope for reducing demand in this way and to the fact that many conservation techniques, such as building insulation and heat recovery systems, are cost effective at present fuel prices and will become more so as relative energy costs rise. A major factor restricting the introduction of such measures is the initial capital investment required - a long-term investment - which is often difficult to justify when in competition with other expenditure providing more immediate benefits. The introduction of government incentives and loan facilities are therefore essential if energy conservation is to make a significant impact before fossil fuel supplies begin to decline. Whereas other countries are already operating such schemes, in the UK the householder may even be faced with an increase in rateable value on installing solar collectors.

Estimates of the energy saving potential of conservation techniques suggest that, if vigorously applied, they could counteract any tendency toward growth in useful energy consumption. It is on this basis that this report proposes a useful energy consumption in 2025 similar to the present figure. The following sections briefly outline the more important conservation techniques available and their energy saving potential in the UK.

Thermal insulation of buildings

Widespread application of cost-effective wall and roof insulation to buildings could reduce space heating demand by 40% on average, yielding a total saving of about 130 million MWh per year. With the existing energy supply structure, this represents a saving in primary energy of around 10%. Higher levels of insulation will become cost-effective if relative fuel price rises continue.

Heat recovery and controlled ventilation

Heat can be recovered from waste water by simple heat exchangers. At present some 50% of domestic water heating energy is lost with the waste water; most of this could be reclaimed, giving a saving of about 30 million MWh of useful energy, about 2% of UK present primary energy. Similar techniques can be applied to many industrial processes.

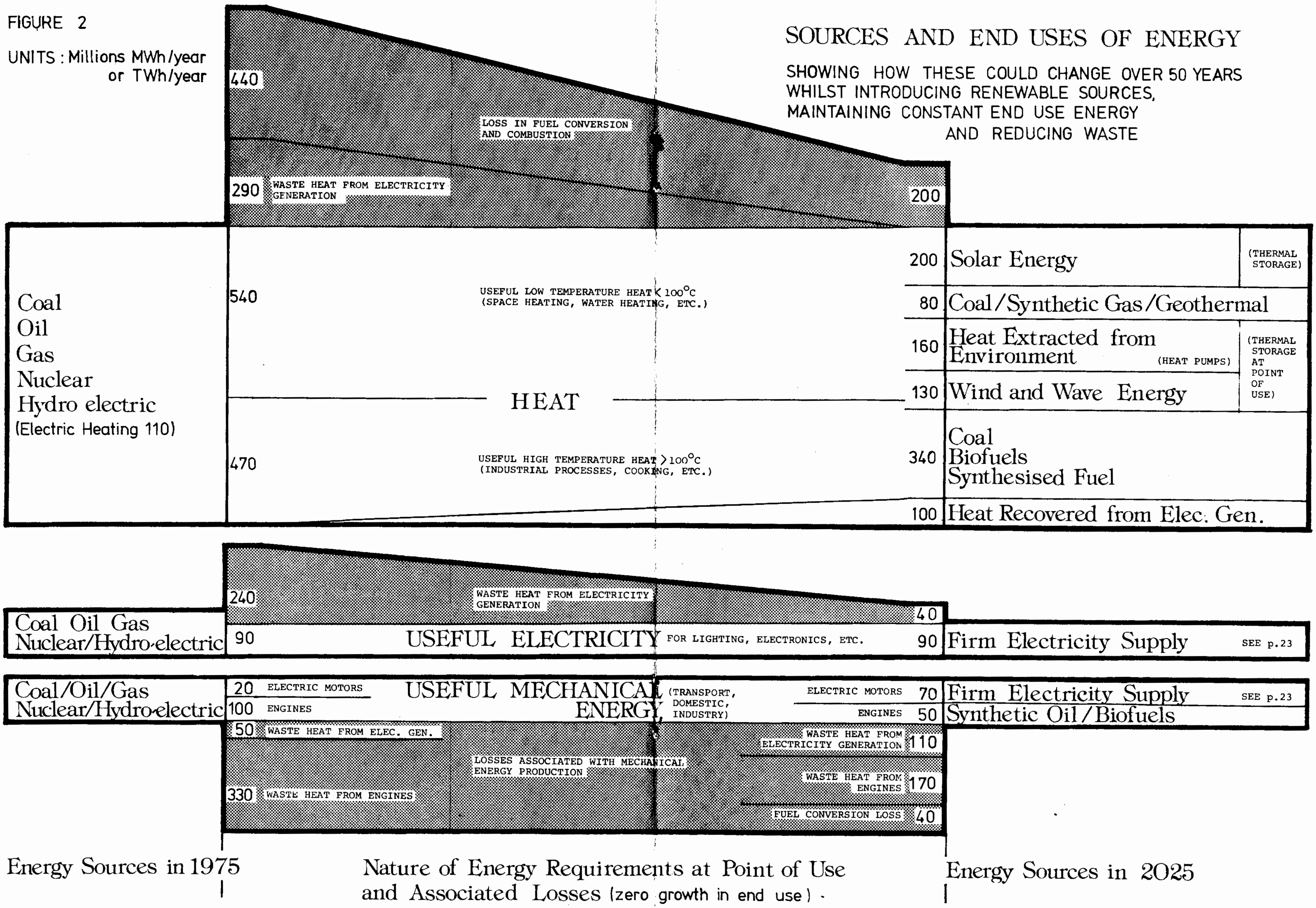
Controlled ventilation systems avoid heat loss through over-ventilation. In addition, heat can easily be recovered from the necessary ventilation air by the use of a thermal-wheel heat exchanger or its equivalent. These techniques can save about one fifth of the space heating energy demand in conventional buildings. The potential saving in useful energy is in the region of 70 million MWh.

FIGURE 2

UNITS : Millions MWh/year
or TWh/year

SOURCES AND END USES OF ENERGY

SHOWING HOW THESE COULD CHANGE OVER 50 YEARS
WHILST INTRODUCING RENEWABLE SOURCES,
MAINTAINING CONSTANT END USE ENERGY
AND REDUCING WASTE



Control Systems

Improved control of space heating systems can yield significant savings. An internal temperature in excess of that required by only 1°C can increase the energy demand by 10%. The use of improved thermostats and individual room controls could reduce accidental overheating and the consequent waste of energy. Sophisticated control systems are now available which are particularly beneficial for intermittently heated public and commercial buildings, where savings of around 25% can be achieved without reduction in comfort levels and at very low cost. New control systems could be introduced very quickly.

Building design

Improved design of new buildings to make optimum use of incidental heat and solar gain, coupled with the incorporation of high levels of insulation and other conservation devices, could make a dramatic difference to the UK energy demand in 50 years' time. Newly built houses need have only one tenth of the space heating requirement of similar sized conventional houses, if an increase in the initial cost of about 10% can be tolerated. A house built recently by Wates Built Homes Ltd has a total energy demand only one fifth that of a conventional house. The current value of the energy saved is similar to the interest payable on a loan to cover the additional cost. To achieve a significant effect over the next 50 years, a requirement for low energy consumption must be incorporated immediately into the building regulations.

Improved efficiencies

Energy is frequently converted from one form to another, usually incurring some loss. Energy conversion efficiencies have improved considerably over the years, but there is still room for further progress. Domestic central heating boilers have a typical efficiency of 60%, whereas there are designs which achieve 80%. Many industrial processes use far more energy than their theoretical minimum, which suggests that considerable improvements are possible. The simple substitution of more efficient lamps (fluorescent tubes, etc) for conventional lighting can make electricity savings of 70% or more for the same lighting levels. These lamps can be made the same size and shape as normal bulbs to facilitate the change.

The conversion of fuel energy to mechanical or electrical energy usually involves low efficiency. The best modern power stations achieve efficiencies of about 35%. Electricity can be produced from fuel at much higher efficiencies by the use of fuel cells, but the models at present available are expensive and of low power ratings. The overall efficiency (fuel to wheels) of cars and vans is typically in the range from 10% to 18%. The rather better overall efficiency (15% to 19%) of electric vehicles (allowing for power station efficiency) means that their increased use in appropriate circumstances would result in a significant fuel saving.

Since transport accounts for about 16% of UK primary energy consumption and generally requires high grade, transportable fuels, it is important to recognise the energy savings that can be achieved through changes in modes of transport, for example by the use of rail, rather than road for long-haul freight and the use of public transport rather than private cars for personal travel. Energy planning should further take into account the overall energy costs of centralised production systems, allowing for their large use of energy for transport. It might well be desirable in the longer term to bring points of production of goods closer geographically to points of consumption. In agricultural planning, greater account should be taken of the energy costs of crops and farm practices in relation to yields.

Energy tariffs and conservation incentives

At present the more energy one uses the cheaper the unit cost becomes. Of course, this is to be expected from the way in which the energy industries are organised, encouraging sales to maximise the return on investment. By contrast, an inverted tariff system, selling energy cheaply up to a subsistence level and more expensively thereafter, would be an effective way of encouraging energy conservation and other energy saving innovations, while safeguarding low income groups, such as old people, who are most vulnerable to rising energy costs.

There is a range of about 2:1 in the fuel consumption of popular private cars. Incentives to choose the more economical vehicles, such as a road tax related to engine capacity, could significantly reduce consumption and stimulate the development of better economy vehicles.

Together with incentives, grants or loans for house insulation, these economic controls could be applied immediately with enormous benefit to the UK by the turn of the century. France and Germany have already started.

4. MATCHING ENERGY SOURCES TO NEEDS

4.1 The Matching Problem

At present almost all the UK primary energy input is in the form of fuels which burn at high temperatures and can therefore be readily converted to other forms of energy, although in practice most of the fuel energy is immediately degraded to low temperature heat energy. With the mixture of sources proposed for 2025, fuel will constitute only about 60% of the input energy. The remaining demand must therefore be satisfied by low temperature solar heat or electricity from other renewable sources. It is therefore important to match each energy source to an appropriate end-use. Most of the renewable energy sources provide a fluctuating power level, unlike fuels which are essentially stored energy and can be converted to power at the rate required. It is therefore necessary to match the source and demand in time as well as quality. To supply fluctuating demands with a fluctuating but often unrelated power source, energy storage is essential. The practical limitations on available storage affect the proportion of the demand that can be supplied by each source. Further considerations are the portability of the energy when stored and the ability to transmit it over significant distances.

4.2 Energy Requirements

In judging the total contribution which can be made by each source, it is necessary to analyse energy requirements in terms of end-use energy. Figure 2 shows the way in which UK present energy use is split between heating (at low and high temperatures), mechanical energy production (for transport, industrial and domestic machines), and electricity (for purposes other than heating and electric motors, such as lighting, electronic communication, etc). The values given in Figure 2 are only approximate as a precise breakdown of consumption in terms of end-use has not been made, and indeed would be exceedingly difficult. They are sufficiently accurate, however, for the purpose in hand. The unshaded bands in the diagram represent useful energy, for example, the heat flowing from a central heating boiler into the house, after deducting the heat lost up the flue, the energy used in supplying the fuel, etc. These bands are projected from the present situation (on the left of the diagram) to a postulated situation in 2025 (on the right) when, following the vigorous application of energy saving techniques, the consumption of useful energy is similar to that in 1975. Without renewable energy sources and serious conservation, the primary fuel which would be needed in 2025 to create the same effect (comfort, mobility, etc) as in the postulated situation would be similar to that estimated by the Department of Energy in their low-growth scenario. The assumed useful energy consumption seems to the authors to be a reasonable and feasible target in view of the large energy savings which can be made, the prospect of a stabilised or falling population, and the approaching saturation effects in housing, industry and general consumption.

The shaded bands represent the energy losses associated with each type of end-use. These are made up mainly of the energy used by the fuel supply industries and waste heat from fuel-based electricity generation, engines and other combustion appliances. The processes by which mechanical energy and electricity are produced from fuel are inherently inefficient, producing between 2 and 5 units of waste heat for each unit of useful energy. It is therefore important to minimise this type of energy conversion in a future energy strategy, unless the waste heat can be utilised.

At present less than half the electricity supply is used for lighting, electronics, etc, for which other forms of supply are not suitable, and although this fraction could be reduced any future energy strategy must include a supply of "firm electricity"*for these purposes.

The remainder of the electricity demand is for electric motors and heating. The overall efficiency of providing mechanical energy from fuel via electricity and electric motors is similar to, and often higher than, that of operating small engines directly from fuel, so this is an electricity use which could be encouraged without a primary fuel consumption penalty.

Heating with electricity is a questionable practice unless heat pumps are used. Creating high grade electrical energy from fuel only to degrade it again into low termperature heat is not only very wasteful of fuel but also, in the case of on-peak heating, requires the existence of otherwise unnecessary generating plant. Electric heating is at present encouraged, not because it is an efficient use of fuel, but to optimise the utilisation of generating plant and the return on investment. On-peak electric heating has the obvious appeal to the consumer that the capital cost of an electric fire is very low, and therefore positive steps would be necessary to curtail its use. There are, however, certain heating applications where electricity can offer other advantages which outweigh efficiency considerations, for example, induction heating, but these are a small proportion of the total.

Most of the present heating demands are met by directly burning fossil fuels at average efficiencies around 60%, and most of the mechanical energy (mainly for transport) comes from internal combustion engines operating on oil fuel at average efficiencies of around 20%.

4.3 2025 Scenario

In the following paragraphs a speculative energy scenario is assembled to illustrate ways in which the projected sources and requirements could be matched. This is not intended as a prediction or as a plan, but merely serves to illustrate the nature of the problem and an approach to its solution.

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* The expression "firm electricity" relates to a supply which is available on demand at all times; "non-firm electricity" relates to an intermittent supply, not always available on demand.

Heating

Low temperature heat energy cannot be converted efficiently to other forms of energy, nor can it be transmitted economically over long distances. Solar energy converted to heat by flat plate collectors is limited by these considerations and, therefore, must be used for low temperature heat loads - space and water heating - and must be collected close to the point of use. The amount of solar energy available is much greater in summer than in winter, whereas the water heating load is fairly constant over the year and space heating peaks in midwinter. It is an easy matter to provide about 50% of the annual water heating energy, but if solar energy is to make a similar contribution to space heating, large thermal stores are necessary, together with relatively large collector areas. However, since space heating is the only other major load which could be met by solar heat, such storage is essential if full use is to be made of this abundant energy source.

Section 2.1 suggests that solar energy installations could provide a total of 198 million MWh of useful energy per year. The 2025 scenario takes a figure of 200 million MWh, as shown in Figure 2. There would be an associated demand for back-up heat which could be provided either by burning fuel (coal, synthesised gas or bio-fuels) to produce heat directly at the point of use, or from wind and wave energy.

It is proposed that another large fraction of the low temperature heating load would be met by heat pumps and resistance heaters powered by non-firm electricity produced from wind and wave energy. The power available from both wind and waves rises to its peak in winter and its availability matches the space heating load quite closely, if short-term fluctuations (upto a few days) can be smoothed out by energy storage. This storage can be associated either with the heat produced or with the electricity supplied. The former method, thermal storage, is much cheaper and would probably therefore be adopted wherever the end use of the energy was heat. If a heat pump is used, the store must be able to accept sufficient heat energy for several days' supply at low temperatures, a water tank or a store using heat-of-fusion (i.e. melting) being most suitable. For economy, the store could be shared between a number of buildings and could be buried underground. Where resistance heating is used, high temperature, and therefore more compact, stores could be used, similar to existing Electricair night storage units. They would be most suitable in the modification of existing houses where space is not available for large, low temperature stores. The input to the heat stores would be controlled automatically by electrical signals, probably super-imposed on the mains supply waveform - a technique sometimes used for street lighting control - so that the power drawn by all the storage loads would match the wind and wave power being fed into the national grid at the time. The grid would carry both firm and non-firm electricity in the same way as it now carries both normal and off-peak loads matched by inputs from different sources. It is important to note that an energy strategy employing a large quantity of nuclear electricity to meet the fluctuating heating loads would also call for widespread use of energy storage.

The 2025 scenario proposes to use approximately 100 million MWh per year of non-firm electricity to drive heat pumps, which in turn draw an additional 160 million MWh per year of heat energy from the environment and deliver 260 million MWh per year of useful heating energy. A further 30 million MWh per year of non-firm electricity is allocated to resistance heating. Together these would call for 130 million MWh per year of electricity from wind and wave power, as shown in Figure 2. (The two sources are grouped together because their outputs vary in a similar way and are, therefore, interchangeable.) Stand-by gas turbines may be required to supplement these sources during infrequent, long, calm spells combined with cold weather, for which it may be uneconomic to provide energy storage.

A further contribution to low and medium temperature heating could be made by the heat produced in generating electrical power from fuel. This would be facilitated by the gradual introduction of small generating stations located near industrial or housing areas. 100 million MWh per year of heat at around 100°C is assumed to be drawn from this source - two fifths of the waste heat produced.

It is suggested that for the foreseeable future most high temperature process requirements in industry and cooking would be met by burning fuel directly. 300 million MWh per year of useful energy is required for these purposes. The energy demand for cooking would probably be most easily met by substitute natural gas or coal gas, although an electric storage cooker (which could operate from non-firm electricity) has recently been developed. Although coal production alone could easily meet this and the other proposed requirements for fuel, bio-fuels could also be used for these purposes, as the various fuels are to a large extent interchangeable.

Electricity and mechanical energy

A relatively small quantity of energy, estimated to be about 90 million MWh per year, is needed for applications such as lighting, communications and other electronics, for which other forms of energy are not suitable. A further amount of electricity is required for operating electric motors. It is assumed that there would be some substitution of electric motors for heat engines in industry. In transport, increased use and extensive electrification of railways and a gradual increase in the number of electric road vehicles is assumed. These changes would raise the total consumption by electric motors to some 70 million MWh per year of electricity.

These electrical loads, totalling 160 million MWh per year, must be met by a firm electricity supply, as shown in Figure 2, (unless several days' energy storage is provided at the point of use). An example of the way in which this could be provided is

coal-fired power stations	100	(350 thermal)
tidal schemes	14	
hydro-electricity	6	
wind and wave power	40	
	160 million MWh per year of electricity.	

The firm electricity requirement would rise significantly in the winter, enabling an effective contribution to be made by wind and wave power without the need for inter-seasonal storage. The relatively small storage required (in the region of 500,000 MWh) to smooth the short-term fluctuations could be provided by pumped storage schemes and compressed air storage schemes. In hydro-electric pumped storage schemes, such as the one already in operation at Ffestiniog in North Wales, surplus energy is stored by pumping water from a low-level reservoir to one at a higher level. Then, when the energy is needed, the water from the upper reservoir is allowed to run back into the lower reservoir through turbines which generate electricity. The existing pumped storage capacity in the UK is approximately 25,000 MWh but it has been suggested that around thirty additional suitable sites exist which could, it is estimated, provide a further 360,000 MWh of capacity. Recent studies in the USA indicate that underground pumped hydro-electric storage could also be developed at acceptable cost in the near future. In such a system the upper reservoir is at ground level, and the lower reservoir is excavated in impermeable rock about 300m (1000 ft) underground. Underground pumped storage can therefore be used in a much wider range of locations. In underground compressed air storage systems, such as that being developed by the Laing Institute in Germany, surplus energy is used to compress air, which is stored underground in large artificial caverns, similar to the one which is being excavated for natural gas storage in Yorkshire by the British Gas Corporation. Then, on days when this stored energy is needed, the compressed air is used to drive turbines and generate electricity.

To supply firm and non-firm electricity demands, the national grid would need to be substantially strengthened, but the costs would almost certainly be less than those of distributing electricity in an energy scenario relying heavily on nuclear power.

The so-called "hydrogen economy" offers an alternative means of transmission and storage of energy. Electricity is used to produce hydrogen gas, which is then piped to consumers who can either use it in fuel cells to generate electricity again, or burn it as fuel in engines and heating installations.

There is a further requirement for about 50 million MWh per year of mechanical energy in addition to that delivered by electric motors. This extra demand is mainly for transport and would continue to be met by liquid fuel. As oil supplies decline, liquid fuel would probably be derived from coal (with significant loss) or from fuel crops, as shown in Figure 2.

5. ECONOMIC AND EMPLOYMENT IMPLICATIONS

A non-nuclear energy option for the period after oil and natural gas have run out has been identified in this paper with a zero or low growth scenario. On the other hand, low growth has been rejected by many on the economic grounds that it will lead to massive unemployment. The argument is that once growth ceases the demand for incremental, non-replacement investment goods dries up; that this causes unemployment in that part of the investment goods sector; that there is consequently less income available to buy consumption goods; and that the reduced demand for consumption goods leads to additional unemployment in other sectors of the economy through a negative multiplier effect.

In recent years, there has been ample evidence to support this contention as, whenever there has been a down-turn in the investment cycle, demand and employment have also fallen. It is therefore difficult to avoid the conclusion that there is likely to be an adverse effect on employment if economic growth ceases, at least in the short term. The question is, however, whether the unemployment will be lasting and whether it will necessarily form an integral part of a society based on non-nuclear energy forms.

Much will depend on the structure of industry which emerges with the new forms. In today's urban/industrial context, the majority of the employed population works in relatively large scale capitally-intensive industries. For them - whether they are skilled or unskilled - the choice is usually between employment in an arena of comparatively high capital outlay or no employment at all. Opportunities for the very small labour intensive business are limited by competition from the larger more capitally-intensive (and energy intensive!) concerns both at home and overseas. Consequently, in a down-turn there is little chance that, if large numbers of people become unemployed, they can create alternative employment themselves with resources which they can afford to obtain from within their own normal savings.

If the present structure of industry survives the energy changes envisaged, then it is likely that a hard core of unemployment will accompany it. If, however, the existence of more decentralised, smaller-scale energy sources, such as solar and wind energy devices, brings about a parallel descaling of industry itself, then it could be that all sorts of new employment opportunities will emerge.

Whether such a radical reconstruction of industry within the next 50 years or so is a realistic proposition is an open question. Although the depreciated life of a large modern industrial plant is about 15 years, its actual life can be at least three times as long. This means that the basis for a long-term UK investment policy which includes consideration of the energy/scale/employment issue must begin to be laid fairly soon.

At present, however, there is little sign that government sees the energy question as one which has implications for decisions affecting other sectors of the economy, and there is certainly not sufficient political will to suggest that it will become a pressing policy issue for some years to come.

6. CONCLUSIONS

This report suggests that, through energy conservation and improved efficiencies, the population of the United Kingdom can maintain an acceptable lifestyle, while improving comfort levels and mobility for certain sectors of the community, without demanding a growth in useful energy consumption.

It further suggests that this stabilised energy requirement could be met by a combination of coal and renewable energy sources for a long period of time, without serious detriment to the environment and without incurring the risks of a large-scale nuclear power programme.

In order to pursue such a strategy, the Government would have to act quickly to encourage the rapid introduction of energy conservation measures and proved systems for the collection of renewable energy, and to channel a much larger proportion of the national expenditure on energy research and development into work related to the use of income energy.

The path suggested, involving a modest expansion of coal production and the development and use of renewable energy technologies, is attractive from the point of view of employment within the energy industry, but the loss of growth in energy consumption could produce a short-term unemployment problem in other sectors until society adapts to living in a steady-state economy.

The adoption of the alternative energy strategy described would be the first step in the inevitable, long-term adaptation to living in balance with income energy sources.

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SUPPLEMENT TO THE 1977 EDITION

ECONOMIC IMPLICATIONS

Energy demand and economic growth

Since the last war, and until the 1974 oil crises, the major industrial nations of the world have experienced continuous and fairly rapid economic growth. Over the same period, the demand for primary energy has also grown at something approaching the same rate. In the UK, the gross domestic product has, until fairly recently, been increasing at an average annual rate of almost 3%, while primary energy demand has gone up at slightly less than 2% per annum. [1]

The relationship between energy use and economic activity has long been of interest to economists and energy analysts. Countries with a high GDP per capita tend to have a high energy use per capita and vice versa. For individual countries, the ratio between growth in energy demand and economic growth (the energy coefficient) has in the past shown surprising long term stability. For most of the period since the war, the UK energy coefficient has averaged about 0.6 to 0.7, whereas in the USA it has been closer to 1.0. It is tempting to draw the conclusion that a firm causal relationship exists between energy use and economic activity, and that therefore a reduction in energy consumption must in future inevitably lead to a reduction in GDP. Energy demand forecasts made by the Department of Energy are based on this assumption. They take the view that future energy supply must be planned to meet the demand which economic growth targets set by Government are bound to generate, and that the energy coefficient which has existed in the past will not change very much in the future. Once this assumption is accepted, it is fairly easy to justify the need for expansion of the UK's nuclear power facilities. Without this expansion, it is claimed, there will be an 'energy gap' in the 1990s and beyond, and thus alternative strategies must be rejected, because according to the official view, they would lead to a shortage of energy, which would hold back economic growth and increase unemployment. [2]

The alternative energy strategy presented in this booklet is based on rather different assumptions about economic growth and its effect on energy demand. For the purposes of discussion three hypothetical future growth paths are considered:

Period	High Growth	Medium Growth	Low Growth
	(Percent per annum increase)		
1975 - 2000	4%	3%	2%
2000 - 2025	3%	2%	1%
GDP in 2000	2.7	2.1	1.6
GDP in 2025 (times present level)	5.6	3.4	2.1
GDP per head, times present level. Assuming 60 million population in 2025	4.9	3.0	1.9

The high growth path resembles that which many economists would like to see for the UK. The medium growth path is a slightly more realistic possibility, and is used in the Department of Energy's reference scenario [3]. The low growth path is the one most likely to be compatible with the alternative energy plan presented in this paper. By steadily increasing the average output/energy use ratio of industry and with the improvements in conversion and end-use efficiency envisaged in such a strategy, an economy of roughly twice the present size in 2025 based on the same consumption of useful energy as in 1975 is not an impossible target. Even if something like the present industrial structure were to be maintained, the scope for improving the specific efficiency of most industries is enormous. For example, it takes 140 x 10^4 k.cal. to produce a ton of cement in the UK compared with only 90 x 10^4 k.cal. in Germany. A ton of aluminium requires more than twice the energy to produce in the UK than it does in the US. [4]

In this scenario it is assumed that industrial structure and consumption patterns will undergo substantial change. It is expected that the service sector will continue to grow relative to manufacturing and that, within the manufacturing sector, the more research intensive industries which make products with a high value/energy index will expand at the expense of more traditional energy consuming industries such as iron and steel, heavy engineering and bulk chemicals.

Official energy demand forecasts assume that present industrial structure will be substantially the same with a slight increase in the relative size of manufacturing [5]. In the Department of Energy reference scenario, energy consumption by industry (including the iron and steel) is assumed to increase by 33% between 1985 and 2000. In view of the fact that between 1970 and 1975 energy consumption in the iron and steel industry declined by 32% and given the rationalisation of the industry which is now planned, such high estimates cannot be taken seriously.

Until fairly recent times, economic expansion and technological progress have depended on the increasing exploitation of cheap sources of energy and raw materials. We now realize that the world's resources are not limitless and that future progress is going to depend increasingly on the efficiency with which these limited resources are utilized. This will mean replacing an economy based on waste and consumption for its own sake, with an economy of 'good husbandry', where scarce resources are conserved as much as possible and where consumption which is wasteful and environmentally damaging is discouraged. For this reason, the pursuit of rapid economic growth which has long been seen as the primary aim of most countries in the world is now being questioned. For the developing nations, growth may be necessary and desirable, but for the advanced industrial nations a continuation of growth rates which have been experienced in the recent past, will probably do little to improve the real quality of life and may, as critics of economic growth like E.J. Mishan and Herman Daly [6] have argued, do much to reduce it. In an advanced country like the UK, the economy is already much larger than it needs to be, to provide every one of its citizens with a satisfying and comfortable life. The fact that a substantial minority of people are without some of the necessities of life cannot be explained as a failure of economic growth; it is a failure of distribution, which no amount of economic growth in the future will automatically solve.

Few but the most fervant technological optimists still believe that our energy use can continue to expand for ever. An alternative energy strategy recognizes this, and the sooner that it is implemented, the easier it will be to make the transition to an economy based on renewable or relatively more plentiful sources of energy. In 1975, largely due to the effects of the 1974 oil crisis, the energy/GDP ratio decreased to 92.2% of the 1973 figure [8]. A number of other countries experienced similar reductions. Furthermore, there is a wide variation between the energy/GDP ratio in a number of different industrial nations *. Sweden, France and Denmark, for example, have a much lower ratio than the UK, Canada or Holland. The countries with high energy/GPD ratios tend to be those countries which have had cheap energy policies in the past. These differences cannot simply be explained by variations in cost of living, climate, or exchange rate [9].

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* Differences of almost two to one in some cases

International comparisons are also useful for revealing some of the shortcomings of GDP/capita as a measure of welfare or quality of life. The GPD/capita of the USA may be twice that of the UK, but very few people who have lived in both countries, would be prepared to argue that life in the USA really is twice as satisfying as it is here; and there are some - including some Americans - who would say that in many important respects the quality of life is actually higher in the UK[10].

Energy use and unemployment

Since 1973 unemployment has been rapidly increasing in most industrial countries. In the UK it now stands at 2½ million, or 6% of the labour force. The same problem exists elsewhere, even in countries in which growth has been more rapid. In December 1976 for example, unemployment rates were 5% in France, 6% in Italy, over 7% in the US and 4½% in Germany [11]. To make matters worse, the working population of the UK is forecast to grow by 170,000 a year in the next five years, so that simply to stop unemployment increasing between now and 1981 means creating 600,000 new jobs in net. In the longer term, it is hard to see things getting much better. The large capital investment in new plant and machinery, which is believed to be necessary to keep our industry internationally competitive, is almost certain to lead to fewer, not more jobs. The dramatic reduction in cost of computer processors and communications technology have only just begun to be exploited. These will have an impact on employment not only in manufacturing but also in the commercial and service sectors of the economy.

The conventional wisdom is that unemployment can only be reduced in the long run by stimulating economic growth. To solve this problem of structural unemployment, however, by growth alone will require growth rates which are quite beyond those which sane economists think are possible. The 3% p.a. growth rate assumed in the Department of Energy's reference scenario will do little to reduce the level of unemployment. The slower rate of 2% p.a. would be little worse in this respect.

There indeed may be a considerable advantage in planning for lower growth instead of constantly making over-optimistic growth forecasts which never materialise. This will at least force us to take direct measures to reduce unemployment instead of hoping that in the future an economic boom will automatically solve the problem [12].

Employment in the energy industries

The energy industries in the UK currently employ over 650,000 people directly and help to support the activities of some 200,000 in the process plant industries, construction and other areas of industry. The energy industries account for about 5% of GDP [13].

A large power reactor construction programme will of course create new jobs, but these will tend to be for highly skilled men and nuclear engineers. These are not the groups most affected by unemployment. Indeed, fears have already been expressed (by the Institute of Power Engineers) that the nuclear programme might actually be seriously hampered by a shortage of skilled manpower.

Alternative energy technologies are far less dependent on esoteric knowledge and can make better use of existing skills and abilities. They are much more versatile, smaller scale and less centralized than the conventional electro-nuclear technology.

The phasing out of the nuclear industry may well have a demoralizing effect on the scientists and engineers who work in it. Some of them will perhaps not relish the prospects of redirecting their efforts and adapting their skills and will seek employment overseas, in Brazil or some other nuclear 'eldorado'. This does not justify going ahead with a large programme of nuclear power plant construction, which is an exceptionally expensive way of creating jobs. The same sums of money if they were spent on renewable power sources and conservation schemes would be bound to create much more employment, and employment of the right type, in the places where it is most needed.

Export potential of alternative energy technologies

The export possibilities for renewable energy power sources and many of the other alternative technologies which will need to be developed look very promising. Unlike nuclear power stations, they can be sold anywhere in the world and they are the kind of technology which most of the developing nations need and will be able to afford.

The past export performance of the British nuclear industry gives little ground for optimism about future export prospects, and the countries which are potentially the best markets have now developed their own nuclear industries. Nuclear reactors cannot be sold to countries which have not signed the non-proliferation treaty and the market for enrichment and reprocessing technology is restricted by the need to limit nuclear weapon proliferation. As Dr. N. Franklin, the Chairman of the Nuclear Power Company has admitted, the export potential for fast breeder reactors is, for both political and technical reasons, very limited indeed [14].

It is a curious fact that since the war the UK has spent a higher proportion of GDP on research and development than any country except for the US and the Soviet Union [15]. A high proportion has been spent on developing 'superstar' technologies in the nuclear, aerospace and military electronics fields. Many of these projects like Concorde and the Advanced Gas Cooled Reactor have been commercial disasters even if they have been technically exciting. In its ever increasing commitment to a nuclear future, the UK seems to have learned nothing from past mistakes.

Because of the very limited export prospects for nuclear plant, the entire cost of development and construction will have to be borne by the electricity consumer or the tax-payer. Although some of the renewable energy sources such as wave and wind generators will be expensive to develop and construct, there is a much greater possibility of offsetting the cost by exporting these to other countries.

Some Problems of Implementation

It has been argued that an alternative energy strategy, while it might be technically feasible, would be virtually impossible to implement for political reasons. The kind of changes in consumption pattern and industrial activity required for it to work would require draconian government measures in the form of high energy taxes and new energy legislation which would make any government which tried to introduce them very unpopular. Some idea of the kind of problems which might be encountered can be gained from the difficulty which President Carter is having in getting US industry to swallow his relatively modest energy conservation proposals.

On the other hand, it is possible to exaggerate the changes in life style which an alternative strategy requires. It does not mean 'freezing in the dark'. It does not mean a decline in living standards. It does not mean a massive exodus to the countryside. It does not imply high levels of unemployment. It does not mean zero economic growth.

The main difficulties will occur in implementing the conservation programme. This will almost certainly be impossible to achieve without substantially raising the price of energy to the domestic and the industrial consumer. Steps will need to be taken to compensate those who might be unfairly affected by this. Single pensioners, for example, at the moment spend more than 10% of their income on heat and light [16]. Poor families in rented accommodation may also be hard hit. Increasing the price of energy to industry is less of a problem than it may seem. In very few industries are energy costs a significant proportion of total production costs. This does mean that more direct intervention may be required to encourage industry to take the necessary conservation measures.

The trouble is of course, that it is much easier for Government to continue with a 'more-of-the-same' policy unless forced to change by some dramatic event such as another oil crisis or a major nuclear power station accident. Meanwhile the possibilities and implications of alternatives to conventional energy policy need to be explored and refined. This paper is only a first step in that directon.

NOTES AND REFERENCES

1. Since 1974 growth rates for GDP and energy use have fallen sharply year by year. Figures can be obtained from the latest Annual Digest of Energy Statistics, HMSO (1977).

2. The clearest statement of the official view on this and other aspects of Department of Energy thinking, is the recently published consultative document (green paper) Energy Policy - A Consultative Document, Cmnd 7101, HMSO (1978), see esp. p. 78.

3. The Department's reference scenario only goes up to the year 2000 during which time it assumes a growth rate of about 3% p.a.

4. Energy Conservation in the International Energy Agency, 1976 review OECD. This useful little book gives a number of other comparisons and makes the point that UK industry is below average in specific efficiency.

5. Energy Policy - A consultative Document, Annex 1

6. LSE economist E.J. Mishan is probably the best known British anti-growth economist. In a series of books and articles, starting with The Cost of Economic Growth, 1967, he has attacked his fellow economists for their belief in the necessity of growth. There are many more Americans in the anti-growth camp. These include the late Kenneth Boulding whose frequently cited paper "The Economics of the Coming Spaceship Earth" is reprinted in Herman Daly (ed) Toward

Steady-State Economy. Edward F. Renshaw's *The End of Progress: Adjusting to a No-Growth Economy*, 1976, is a useful recent contribution to the debate. Robert Heilbroner's *An Inquiry into the Human Prospect*, 1976, is a thought-provoking discussion of some of the problems raised by resource limitations. On the diminishing marginal utility of increasing consumption, Richard Easterlin, "Does Money buy Happiness?" *The Public Interest* (Winter 1973), Staffan B. Linder *The Harried Leisure Class*, 1970, and Tibor Scitowski *The Joyless Economy*, 1977, are all recommended. An intriguing attempt to modify economic theory to take account of the laws of thermodynamics is Nicholas Georgescu-Roegen, *The Entropy Law and the Economic Process*, 1971.

7. See for example Fred Hirsch, *The Social Limits to Growth*, 1977, and A.B. Atkingson, *The Economics of Inequality*, 1977.

8. *Energy Conservation in the International Energy Agency*, 1976, p 14.

9. A study by Lee Schipper and Allen J. Lichtenberg, "Efficient Energy Use and Well-Being; The Swedish Example", *Science*, 3rd December 1976, brings this out very clearly.

10. This is one of the main points of Scitowski's *The Joyless Economy*. It was written after Scitowski, a Stanford economist, had spent a sabatical in Europe.

11. Bureau of Labour Statistics, US Dept. of Labour, in *Social Trends*, HMSO, 1977.

12. See for example *Structural Determinants of Employment and Unemployment*, OECD, 1977. The kind of measures being discussed include such things as reducing the working week, sabaticals for workers, early retirement, job sharing schemes.

13. *Energy Policy - A consultative document*

14. In a talk at Birmingham University on 11th February 1978.

15. Over 2% of GDP. Two thirds of this has been spent on nuclear, aerospace and electronics.

16. The rapidly escalating costs of nuclear power plant construction in the USA have been the subject of great debate. According to Barry Commoner in *The Poverty of Power: Energy and the Economic Crisis*, 1976, if present trends continue, nuclear electricity is never going to be cheaper than electricity from coal: As a straight forward economic proposition, it does not look very attractive even *with* breeder reactors.

17. *Social Trends*, HMSO, 1977.

NOTES ON AUTHORS

This report gives a borad outline of a proposed alternative energy strategy for the UK for the period upto the year 2025, but does not claim to be comprehensive either in its treatment of the various energy topics or in its assessment of the social implications of the strategy proposed.

The authors have wide experience in energy matters, and can speak with considerable authority on the broad question of long-term energy policy.

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