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Energy Conversion to Electricity

D. Clark

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Energy conversion to electricity

By D. Clark
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[Two plates]

Growing awareness of future problems of supplies of hydrocarbon fuels enhances the importance of nuclear power in meeting continuing growth in the demand for energy, and of electricity as the route for the deployment of nuclear power. Acceleration of the growth of the electricity share of the total energy market and of the substitution of electricity for other fuels will entail the reversal of some of the trends of the past decade in the United Kingdom.

The scope for innovation in the technology of conversion of fossil fuels to electricity will be limited in the United Kingdom by future contraction in investment in fuel-fired generating plant. Uncertainty about primary fuel supplies and prices in the medium term calls for flexibility in fuel use during the transition to a mainly nuclear system. A continuing task is the harmonization of the expansion of electricity production with the preservation of the environment.

The electricity industry differs from the coal, oil and gas industries in being only to a minor extent a producer of energy – from water power. It is essentially a converter of energy. Its product inescapably reflects the costs and reliability of its primary fuel supplies. On an energy content basis electricity is bound to cost more than the primary fuels from which it is generated; it sells on versatility and convenience and efficiency at the point of use. The electricity industry of the U.K. is the biggest buyer of primary fuel in Europe. It has a vested interest in looking critically and impartially at all the primary fuels.

Historically coal was unchallenged in the power stations until the mid-1950s. Then oil began to offer lower costs and more reliable supplies in the immediate future; and nuclear power for the longer term. Diversification began to take effect in the late 1950s; stimulated by government in the case of nuclear power and alternately stimulated and impeded in the case of oil.

Figure 1 shows, on the left, the C.E.G.B. generating-plant mix early in the present decade. The system can produce electricity from four primary sources. But it is still predominantly a coal-fired system. European electricity industries collectively have a rather smaller proportion of nuclear plant and a considerably bigger proportion of oil-fired plant.

However, in the worst period of electricity rationing during the coal strike of 1972, when C.E.G.B. electricity production was cut by a third, just about half of the reduced output came from nuclear, oil and gas-fired generation.

Because of long manufacturing times much of the plant for installation in the present decade is already committed. By the early 1980s the C.E.G.B. plant mix will look something like the right-hand column. Users of electricity will be better cushioned than at any previous time against interruptions in supplies of any one of the primary fuels.

We naturally tend to think of indigenous coal as being more secure than imported oil. But continuity of supply does not depend just on which country controls the reserves. It depends on people; on the will of producers and workers to maintain a reliable flow of fuel. Over the past 15 years electricity production has been hit harder by coal stoppages than oil stoppages. Short-term interruptions to either must be expected.

Adjusting the mix of plant to match a changing fuel situation is a slow process, because it takes a long time to get new plant manufactured or existing plant converted. What is even more valuable than diversity of plant by itself is to have flexibility to change the fuel mix at short notice. The British electricity system now has a growing capability to do this. It derives from, three factors: the diversity of generating plant already described, the strength of the supergrid, and the unified control of plant loading.

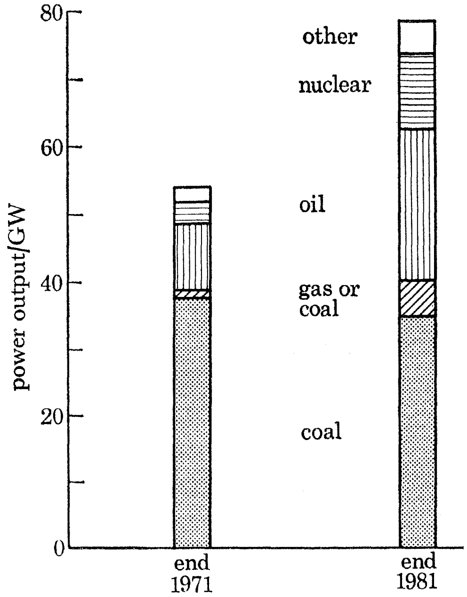

FIGURE 1. C.E.G.B. plant 1971 and 1981.

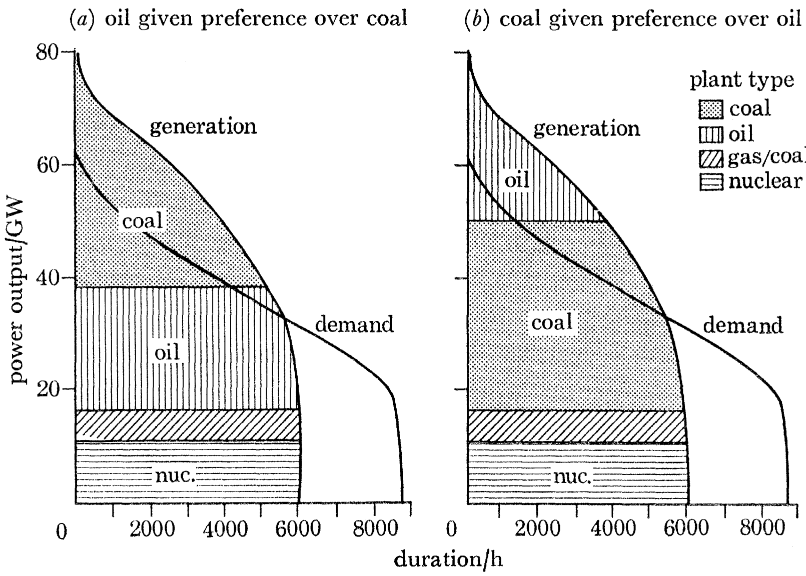

FIGURE 2. Simplified diagram of C.E.G.B. plant loading in 1981.

Electricity cannot be stored so generation must take place round the clock; and there must be enough generating plant to meet the peak demand. For most of the time electricity consumers take less than their peak demand, and when they do a choice can be made as to which plant to run. Plant is normally put on and off load in order of merit in terms of operating costs.

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Figure 2 shows in simplified form the equivalent hours of full load operation of plant, as predicted for 1981/2. The plant with lowest estimated operating cost is stacked at the bottom and runs for the longest periods at full load. In 1981, nuclear plant will still be well within the high load factor area. The left diagram is on the basis of oil being given preference, either on account of price or availability; and the coal-fired plant running for shorter hours. The right-hand diagram shows coal given preference; and the oil plant running for shorter hours. The shaded areas show broadly the potential for producing electricity from each fuel.

Geographically the big oil-fired power stations are on the coast, near refineries. The big coal-fired stations are mostly inland, in the East Midlands and Yorkshire. A switch of preference means big changes in the power flows over the supergrid, but it has been designed with the capacity to handle them. It is this capacity that makes it possible to get substantial flexibility of fuel use from a system made up mainly of single-fuel power stations; as well as securing the classic economies of an electricity grid system.

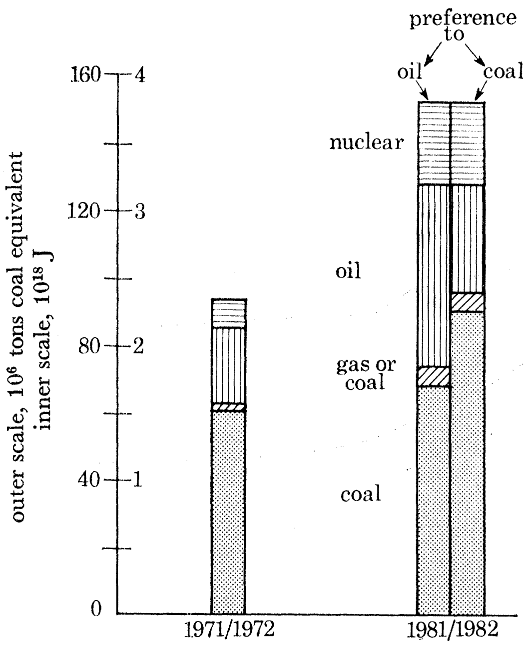

FIGURE 3. C.E.G.B. fuel mix 1971 and 1981.

Figure 3 shows the mix of fuel consumption that results from the plant shown on figure 1. On the left, the actual mix early in the present decade is shown; on the right, the estimated range of possibilities for the beginning of the 1980s; left side, oil given preference; right side, coal given preference. At the present time the range of flexibility as between coal and oil is $2.5\text{–}4.0 \times 10^{17}$ J. By 1981/2 it will be at least 5.0×10^{17} J. Using existing and committed coal-fired plant the C.E.G.B. stations will be able to burn over 90×10^6 tonnes of coal a year if availability and price are right. Scottish stations would add roughly 10% to that capability.

This means that as well as having the largest coal industry in Europe, Britain has an electricity system more than capable of absorbing all the indigenous coal that is likely to be available, at least into the early 1980s. Note also that it is an electricity system still dependent on coal for, as a minimum, half of its fossil fuel requirements.

The foregoing describes what the electricity industry is doing to diversify its fuel supplies;

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and, as a major fuel user, to create flexibility to respond to unforeseen events. This is the setting in which energy conversion to electricity in the 1980s has to be seen.

In the years between now and 1980 world fossil fuel supplies may well be difficult – at least intermittently. Conceivably, over-reaction could cause a swing back to surplus; but there is wide agreement that other energy supplies need to be expanded in the 1980s. Tidal power and geothermal power will be limited and local. Solar power cannot be counted on for much in the 1980s. Nuclear power, fission power, is the main hope. Figure 2 shows how much scope there is for additional nuclear plant to operate at high load factors in the U.K. In its early days nuclear power had to face falling real costs of fossil fuels, but for the future the position is likely to be reversed. It is quite possible that nuclear power will become economic and practicable for lower load factors by the time these are imposed by the system.

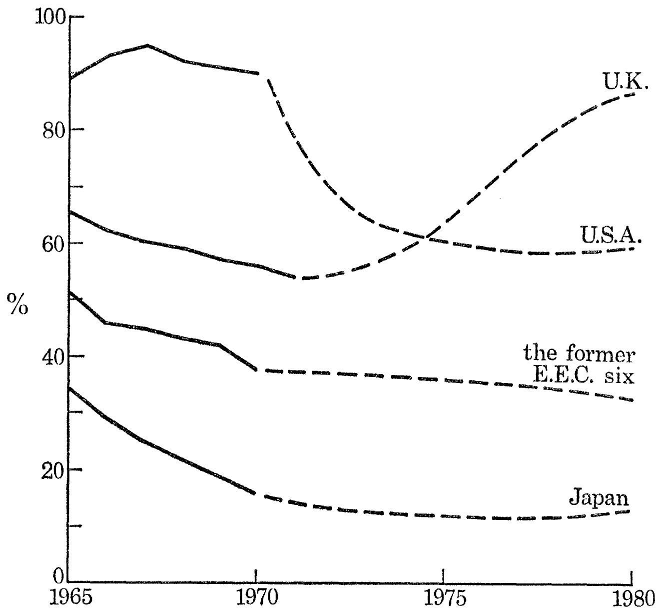

FIGURE 4. Indigenous energy as percentages of primary energy demand.

Figure 4 illustrates the point made by the Secretary of State, namely that in the U.K. North Sea oil will lead to a rising trend towards oil self-sufficiency and towards overall energy self-sufficiency. The build-up portrayed for the U.K. may prove to be a little optimisitc, but even allowing for that, it is in sharp contrast to the prospects for other major industrial countries. The electricity industry looks on this prospect as supporting the continued construction of a limited number of oil-fired power stations in the U.K., but only to bridge the capacity gap before a renewed programme of nuclear construction can take effect. By the middle 1980s nuclear power ought to be providing the whole of the increase in energy for electricity production; and be helping to sustain a high level of energy self-sufficiency in the U.K.

Figure 5 shows the cumulative ordering of nuclear plant in recent years. There are two main reasons for the hiatus in the U.K. since 1969. First, the low rate of electricity growth which meant that very little new plant of any kind was wanted. The second factor was the discouraging experience with the contracts for the a.g.r. stations that were ordered between 1965 and 1969. With rather better electricity growth the slack in plant on order is largely taken up and there is room for substantial nuclear ordering for the 1980s.

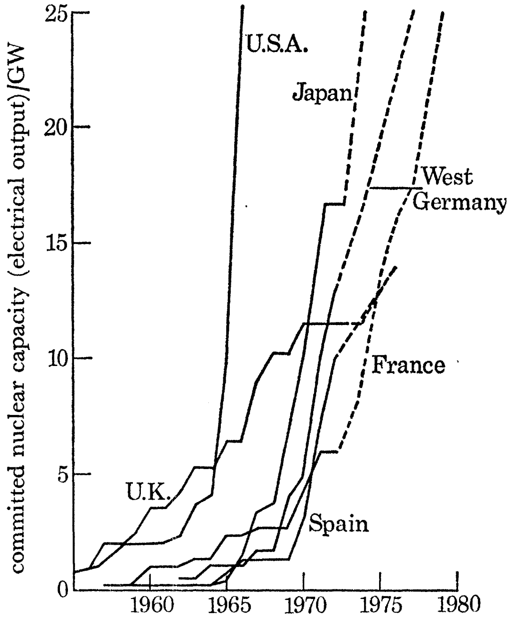

FIGURE 5. Cumulative orders for nuclear plant.

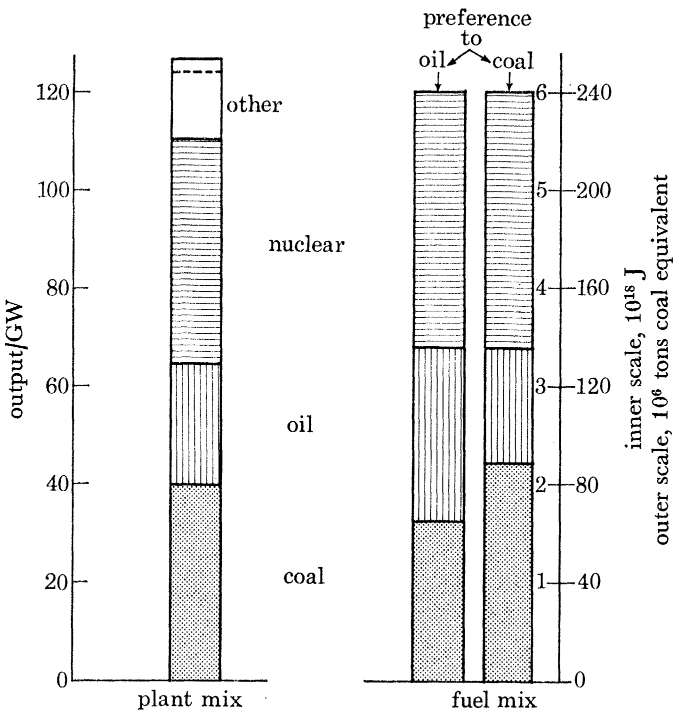

FIGURE 6. C.E.G.B. plant and fuel mix 1990.

If we assume that in the 1980s electricity growth will be at a rate of 5% per annum in maximum demand, then the capacity of generating plant to be added to the C.E.G.B. system in that decade would be about 55 GW. Given an early choice of reactor system some three-quarters of that might be nuclear plant, coming into service at a rate of about 2 GW per annum in the early 1980s and building up to between 5 and 6 GW per annum in the second half of the decade. The remaining one-quarter would include both peak load plant and fossil fuel steam-plant, the choice between coal and oil depending on the trend of supplies.

Figure 6 shows on the left the resultant mix of C.E.G.B. generating plant at the end of the 1980s and on the right the resultant mix of fuels. The assumed split between coal and oil is very tentative and again there is considerable flexibility at the interface.

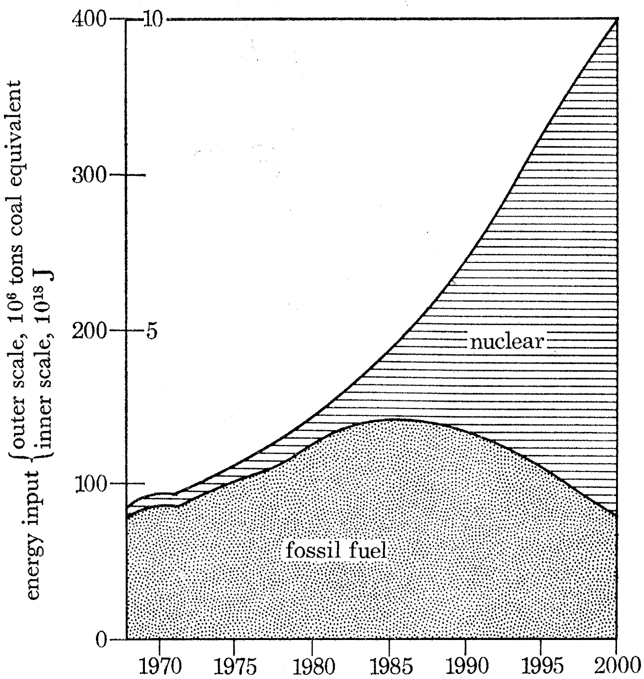

FIGURE 7. C.E.G.B. energy input forecast.

Figure 7 shows the possible split between nuclear and fossil fuel input over a longer period. Note the periods of zero expansion of nuclear generation – at the present time while waiting for the a.g.rs and at about 1980 while waiting for the new programme.

Neither my remit at this conference nor discretion will allow me to digress into reactor choice. But both the energy situation and the needs of the electricity industry make the same demand. Nuclear power is promoted from being just the savoury to the meal to being the main course for the future. What is urgently wanted is to get on to a steady diet of good, well-proven, 'bread and butter' plant. Indeed, this is vital if nuclear power is to achieve its potential in the 1980s. More venturesome technologies can be blended into the basic programme later on. Such a programme will call for all the scientific and engineering skill that this country can bring to bear.

In the case of fossil-fuel conversion technology, the scale of future generating plant ordering in the U.K. will be too small for major technological innovation to pay off – at least in the case of steam plant. Steam turbines suited to water reactors would be essentially adaptations of designs already existing or under development. For other reactors with higher steam conditions some modifications to past practice are probable, such as the use of steam-to-steam reheat in order to simplify the nuclear steam supply system. Unit sizes roughly double the present 660 MW are also probable in the 1980s, though if 1300 MW reactors are built at an early stage they will probably each have two 660 MW turbo-generator sets.

Peak load plant, though a small proportion of the total, is likely to be installed on an expanding

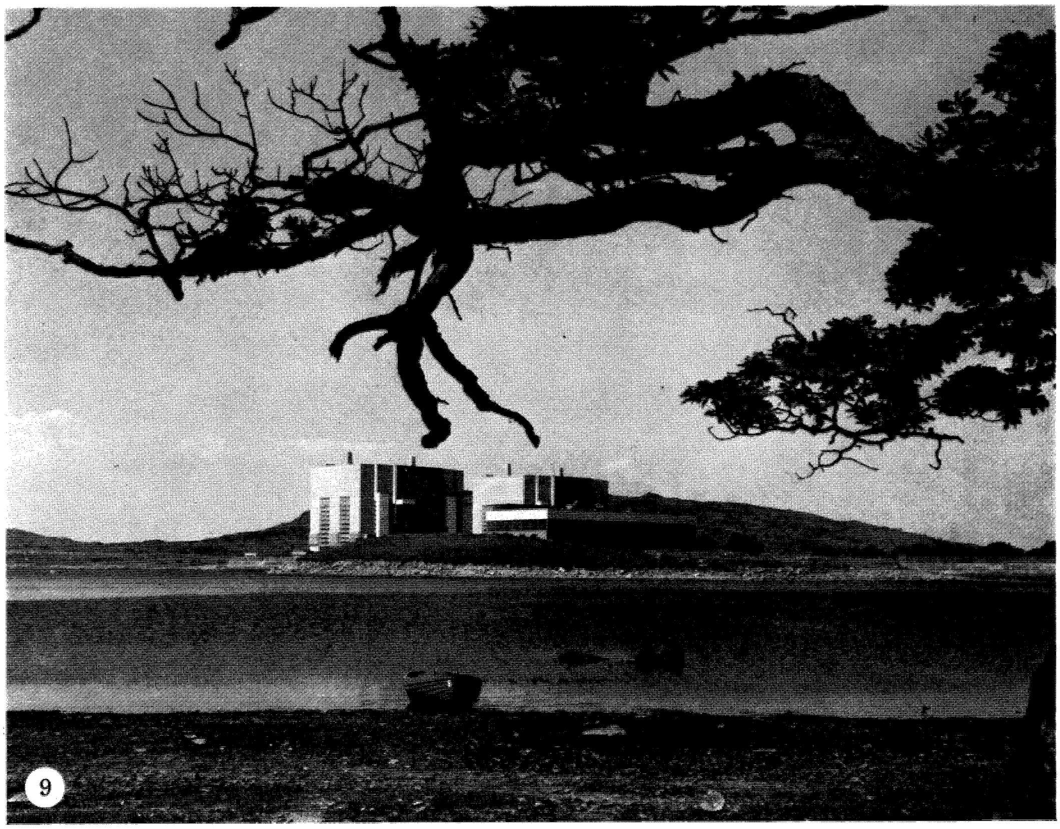

FIGURE 8. Ffestiniog pumped storage station.
FIGURE 9. Trawsfynydd nuclear power station.

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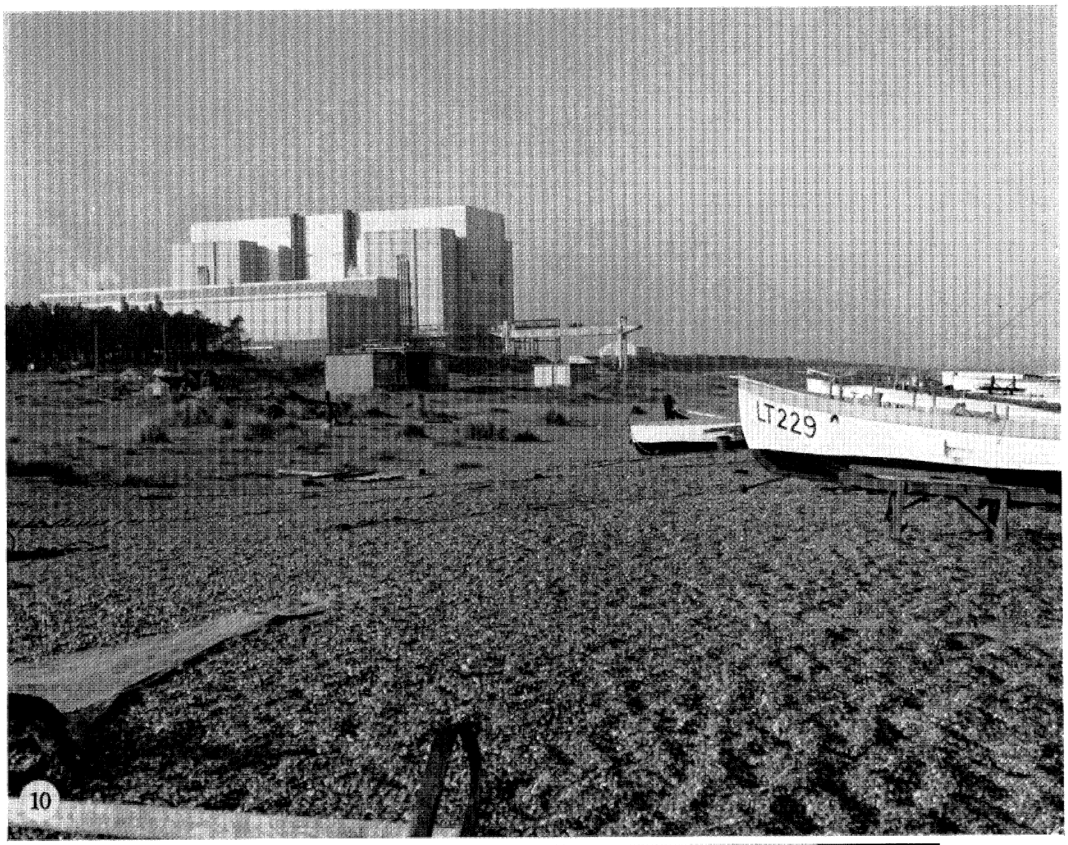

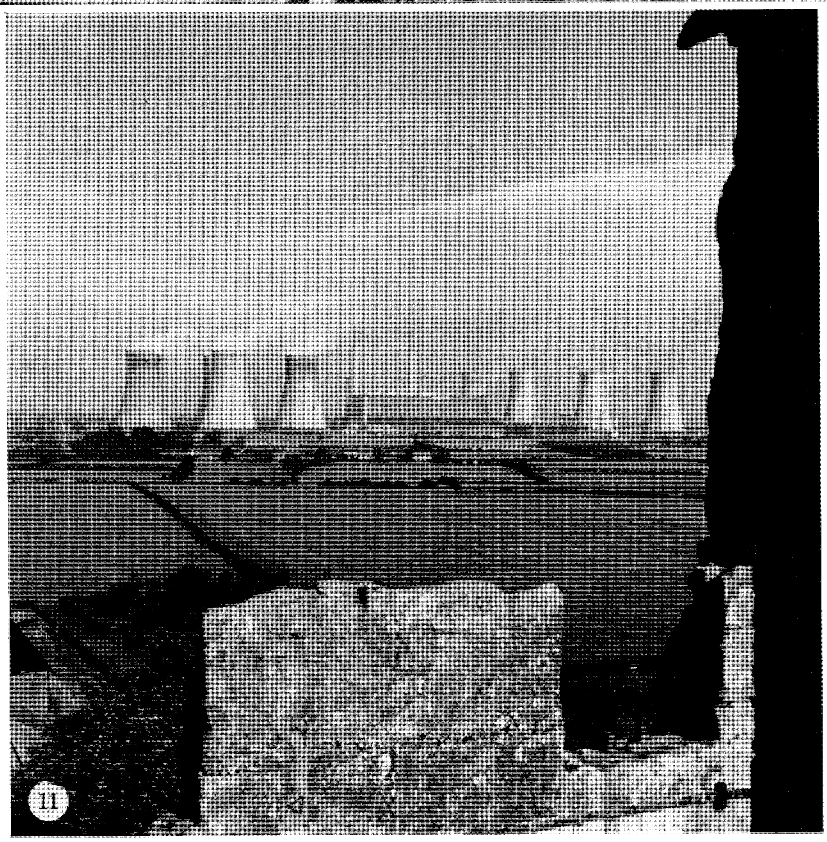

FIGURE 10. Sizewell nuclear power station.
FIGURE 11. West Burton power station.

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scale. Gas-turbine developments will probably continue to lean heavily on the much larger investment for aircraft propulsion.

The pumped-storage version of energy storage is particularly valuable because hydraulic machines give a faster and more assured response to instant demands for more power generation. Other forms of energy storage will come in for increasing attention because, towards the end of the 1980s, low-cost surplus nuclear generation will become available on a sufficient number of nights of the year to improve storage economics.

The environmental implications of energy growth are as important as the technology. The electricity industry of the U.K. has done more to harmonize the expansion of electricity production with protection of the enrivonment than any other electricity industry that I know. Great care is given to the planning, siting and design of every new power station. Decent appearance of a plant in its setting is a prime requirement. An ugly or untidy plant creates hostility, and the suspicion that it pollutes the air and water as well as the scene.

Figures 8–11 show examples of British power stations. Figure 11 illustrates a problem at inland sites, namely that the cooling towers bulk larger in the landscape than the power stations themselves. And inland sites are unavoidable because many stretches of the remaining undeveloped coastline are among the areas most worthy of preservation.

To ameliorate this the C. E.G.B.'s research and engineering departments have developed a new fan-assisted design of cooling tower. The first will be used at the Ince 'B' oil-fired power station now under construction. One tower will cool 1000 MW of plant, which previously required three or four natural-draught towers having the same chimney dimensions. Two towers will suffice for a station the size of West Burton. Later it is hoped to develop the new type of tower to 2000 MW capacity. A more intractable problem with cooling towers is the appearance and persistence of the vapour plumes in humid weather. A so-called 'dry' cooling tower has been in use at Rugeley Power Station for many years. There is no vapour plume in that case, but the tower is much bigger and more expensive than a wet tower. A study is being made of the possibility of a hybrid tower which might reduce the vapour plume without unduly inflating bulk and cost.

In the case of coastal and estuarine locations, experience and research has shown that with careful design very large quantities of warm water can be discharged without harm to the ecology.

Figure 12 illustrates a topical example. Recently a newspaper magazine published an account of 'a huge settlement of ten million oysters found in the Solent'. This figure shows a contour map of the density of the oysters on the seabed. Several factors are advanced by the biologists to account for this sudden occurrence of oysters in Stanswood Bay. In addition there is a fascinating coincidence. Fawley power station is one of the biggest in the country and the tunnels discharging the warm water terminate right where the oyster bed has appeared. The big spatfall that started the new bed is believed to have taken place in the summer of 1970. Fawley Power Station began effective operation at the end of 1969. Evidently not all change is for the worse.

A continuing environmental objective is to limit the proliferation of power stations by putting as much capacity on each site as the technology of the day permits. In 1960 the biggest output from a single site in the U.K. was 1000 MW. Today it is 2500 MW. Sites suitable for over 4000 MW have been identified. A study is being made of the problems of 10000 MW groupings, and how to solve them. At the other end of the size spectrum, enough is known about the environmental aspects of gas-turbine stations to allow them to be located close to load centres.

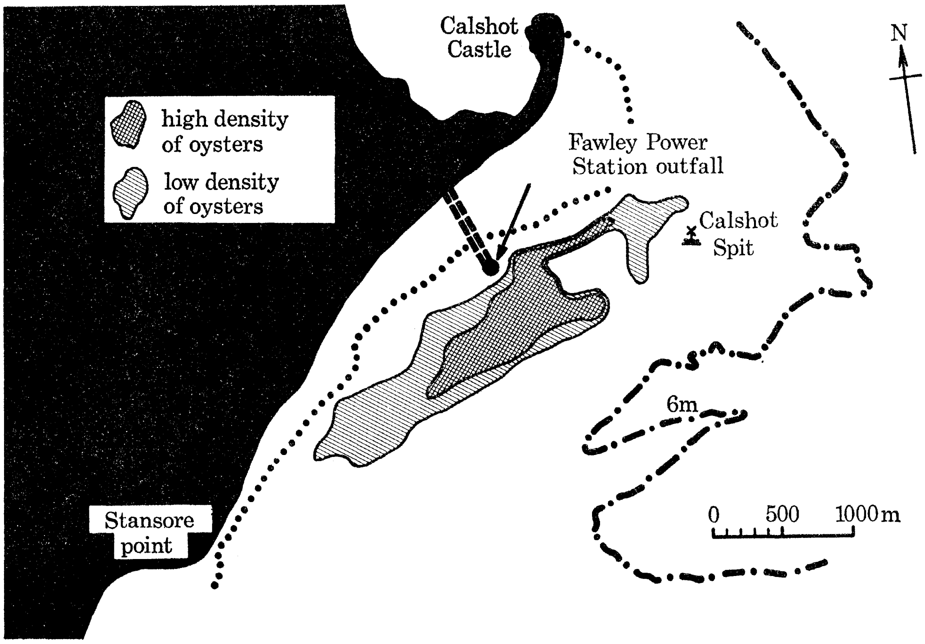

FIGURE 12. Stanswood Bay oyster bed.

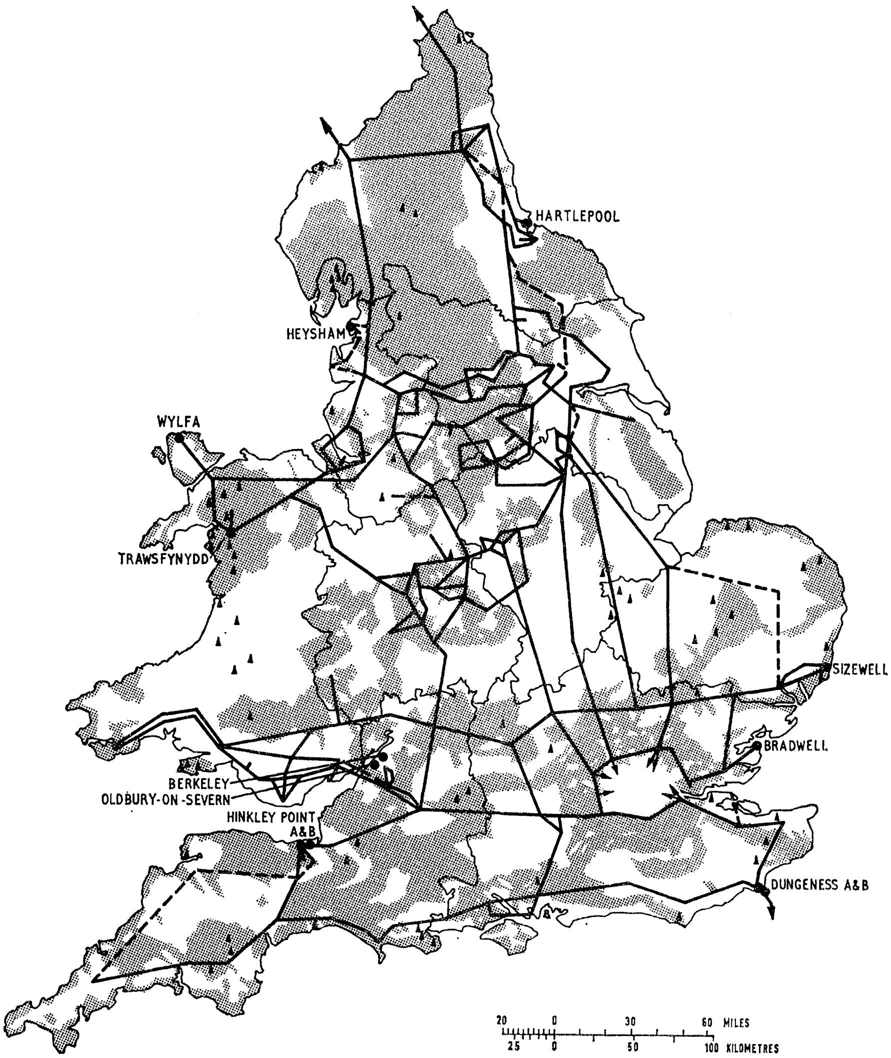

FIGURE 13. Supergrid (—, operational; – – –, projected) and protected land (shaded area) including National Parks, Areas of Outstanding Natural Beauty, Areas of High Landscape Value, Forest Parks, and Green Belts (approved and under consideration). ▲, National Nature Reserve; ●, nuclear power station sites. Standard region boundaries are also shown.

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Nuclear generation eases one problem because the transport of fresh fuel to the stations and of spent fuel to the reprocessing plants is on a small scale compared with fossil fuels. Remote siting for safety reasons is apt to be objectionable environmentally, and it is now largely a psychological point. The real safeguard for any nation needing nuclear power is a rigorous standard of integrity in the design, manufacture, operation and maintenance of its nuclear installations.

Figure 13 shows the supergrid system in England and Wales superimposed on a map of the areas which are specially valued environmentally. It is a multi-purpose system; it interconnects all the major power stations and gives bulk supplies to the Area Electricity Boards for distribution. At 1960 the capacity of the biggest line was 1000 MW at 275 kV. Today it is 3500 MW at 400 kV. Means are being explored of getting 5000 MW on one 400 kV line in the future. The main framework of the supergrid is now expected to be adequate through the 1980s. Local additions will be required, mainly to connect new power stations. Research into higher voltages is well in hand in case of need. A direct current cable link is being brought into service within the a.c. network to gain experience of costs, problems and performance.

All in all, there are good grounds for believing that the electricity expansion of the 1980s can be harmonized with effective care for the environment.

I would like to finish with a speculation about energy use to the end of the century, and a possible question for discussion.

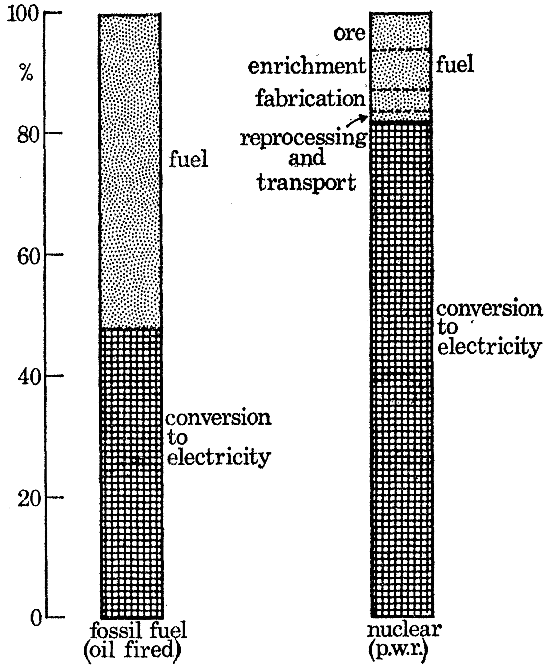

Figure 14. Cost structure of electricity production.

Figure 14 shows the relative delivered fuel costs and other costs of producing electricity from fossil fuel and nuclear fuel. The fossil fuel supplier plays a major role in both the cost and reliability of electricity production. With nuclear power the fuel supplier has a lesser role. Ore costs and quantities are small enough for stocks to be kept in terms of years rather than weeks of consumption. For practical purposes nuclear energy is indigenous, and at present electricity generation is the only route by which it can be brought into the nation's energy economy. Electricity producers, therefore, assume more of the role of primary energy producers. As time

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goes on this implies a broadening of their responsibilities and outlook – asking not only 'Are we supplying the demands of our customers reliably and economically?' but 'Are we making the right contribution to the energy resources of the country?'

Figure 15 shows a speculation about the market shares of secondary energy, in terms of useful energy delivered to consumers. The coal, oil and gas areas shown excludes their use for generating electricity. To 1972 it is factual. For the future the key assumptions are:

(1) Total end energy use growing at about 4% per year (corresponding to a lower figure for primary energy).

(2) Coal use, except for conversion, e.g. at power stations, falling to 20×10^6 tonnes per year by the end of the century.

(3) Gas levelling off at 20×10^{17} J per year.

(4) Electricity growing at about 5% per year.

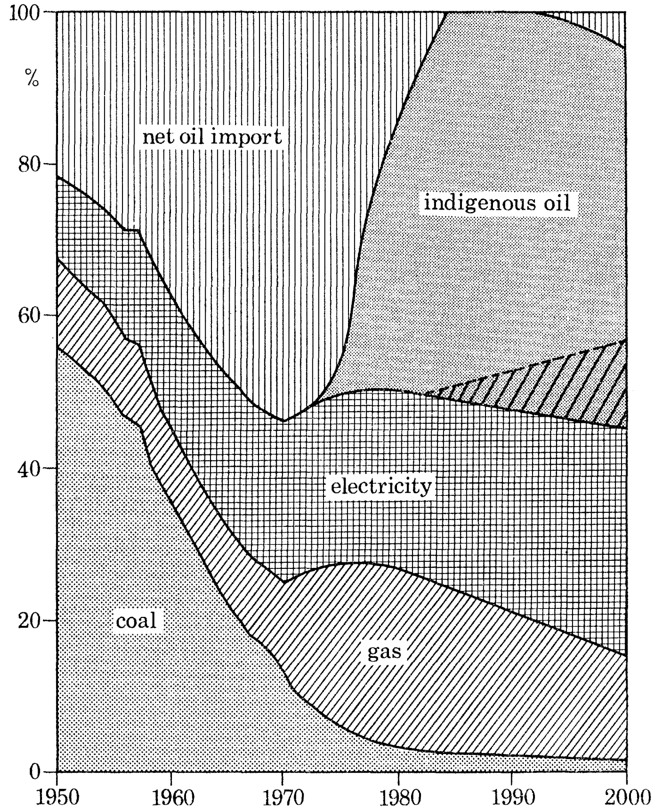

Figure 15. U.K. energy market shares.

With this projection the electricity share of the market would grow to 30% by the end of the century; and nuclear generation would be meeting 23% of the total end energy supply.

Oil consumption would still be high, even after allowing for falling use at power stations. The figure shows an optimistic view of indigenous oil production; it might fall well short.

The question arises: are the fossil fuel prospects so gloomy that faster expansion of nuclear power should be the aim?

By way of illustration, the cross-hatching shows electricity taking a larger share of the secondary energy market so that by the end of the century nuclear generation would be supplying 34% of the country's end energy consumption. This would mean boosting electricity growth to 7% per annum from the early 1980s. It would also mean substituting electricity for oil over something like 20% of the oil market. The lead time required would be long. The need for it hinges largely on the longer term prospects for oil from the continental shelf. Energy decisions of this kind call for some heroic forecasting. The views of the oil industry would be of the greatest interest.

Discussion

PROFESSOR E. EISNER (*Department of Applied Physics, University of Strathclyde, Glasgow*)

Use of rejected heat. May I start by thanking Mr Clark for a contribution of great interest and exceptional clarity, and particularly for slides that one could easily see and understand? I have two questions for him.

(1) In comparing capital investment costs and running costs, what interest rate is used?

(2) I have learned from Mr Clark that, by 1990, the Central Electricity Generating Board is proposing to reject about 200 GW of heat from its power stations. What is it proposing to use this heat for?

I was delighted to see the slide showing the flourishing oyster beds at Fawley, but disappointed to see that Mr Clark only regarded this as showing that waste heat from power stations did not need to be destructive. Why be so defensive about it? Why not regard the rejected heat as an asset whose use must form a part of the calculation of the use of existing power stations, and the design of future ones? And why not regard the oysters at Fawley as a demonstration of what some of us have been advocating for years?

Molluscs, and particularly the mussel, are among the most efficient known converters of sunlight into animal protein. Their efficiency of conversion depends strongly on water temperature, largely because of the rate of growth of phytoplankton. At present, the growing season in Britain is largely limited to about 3 months, but this would not be at all necessary if the mussels were grown in a fairly confined fall-out from a large power station. We spend some £200 million of foreign exchange a year on animal feedingstuffs, and I suggest that it is at least possible that we could easily save all of this using existing power stations.

I am sure that similarly valuable uses could be found for a very large part of this heat, which is at the moment wasted. In inland power stations, it seems to me that there is a prima facie case for considering horticulture in ground heated by the pass-out water. Any one who has experienced the poor quality and choice, and the high price, of lettuces and other horticultural products in Scotland will share my view that it will probably pay now, and even if it does not, it soon will with the rise in world food prices.

These, however, are only the sorts of things that could use heat from existing power stations, passing out at, say, 30 °C. If the principle of selling heat were an integral part of the design of new power stations, I am sure that the sale could profitably be at a price that would attract customers, especially with the rising price of fuel. Naturally, one would have to pay more per joule for warmer water. If such customers were sought as a matter of routine in the design of power stations, the enormous capital cost of the low-temperature end of generation could be saved, as well as the cost of getting rid of the heat.

What I am asking for is that the use of the low-temperature heat should be treated as part of the system being designed.

What work is the C.E.G.B. doing on these questions?

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Mr R. V. Watts (*The Hatfield Polytechnic, Hertfordshire*)

Sir Eric Drake, in his paper, demonstrated that natural oil supplies were unlikely to be able to meet the demand from 1978 onwards. Oil has considerable value as a source of raw materials, as well as energy, it is also the most convenient source of energy for transport applications. These factors are likely to lead to available oil reserves, whether indigenous or not, acquiring considerable economic value and it was particularly disappointing to see the significant planned increase in the use of oil for electricity generation by 1981. As Mr Clark himself demonstrated, the electricity generating industry is well able to use alternative energy sources, in particular, it is probably the only major industry capable of making direct use of the large reserves of coal previously mentioned.

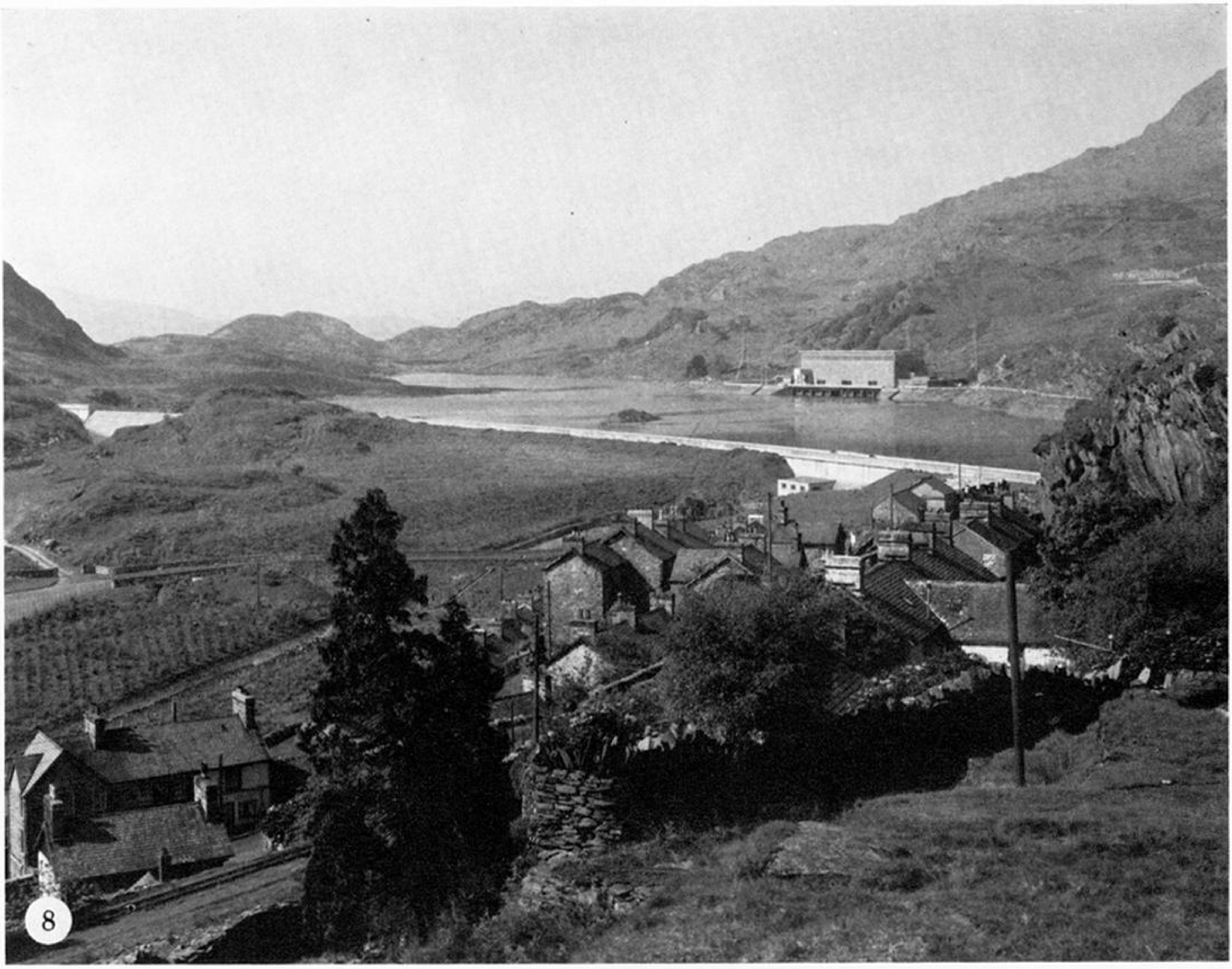
With regard to problems of energy storage associated with the increasing proportion of electricity from nuclear power stations, attention should be drawn to the considerable market for hydrogen implied by the proposals for the manufacture of s.n.g. and synthetic crude from coal. Thus, although, the 'hydrogen economy' may be too distant to consider very seriously, there may be scope for an indirect contribution by nuclear energy to the non-electricity market, by the production of hydrogen in off-peak periods for processing purposes.

Sir Peter Kent, F.R.S.

Mr Clark raised the question of whether it was reasonable to regard the present U.K. oil imports as replaced by the equivalent amount of indigenous oil from about 1977 onwards (his figure 15). In answer, Sir Peter Kent suggested that although the total quantities in the North Sea might well be correctly forecast (although including much oil as yet undiscovered), the physical conditions, the necessity to stretch engineering technology far beyond existing standards, and delays in availability of scarce highly specialized marine equipment would all operate strongly to produce slippage in off-take dates. The oil may not, in fact, be available as soon as was optimistically assumed.

Beyond this, it could conceivably be future policy that once the immediate energy gap has been passed, the remaining oil might be produced at a lower rate to make it available over an extra 10 or 20 years for specialized consumption.

There is, in consequence, good reason to believe that in Britain nuclear power will be required in greater quantity than shown on Mr Clark's minimal forecast, with an escalation of 7% per annum or rather more.



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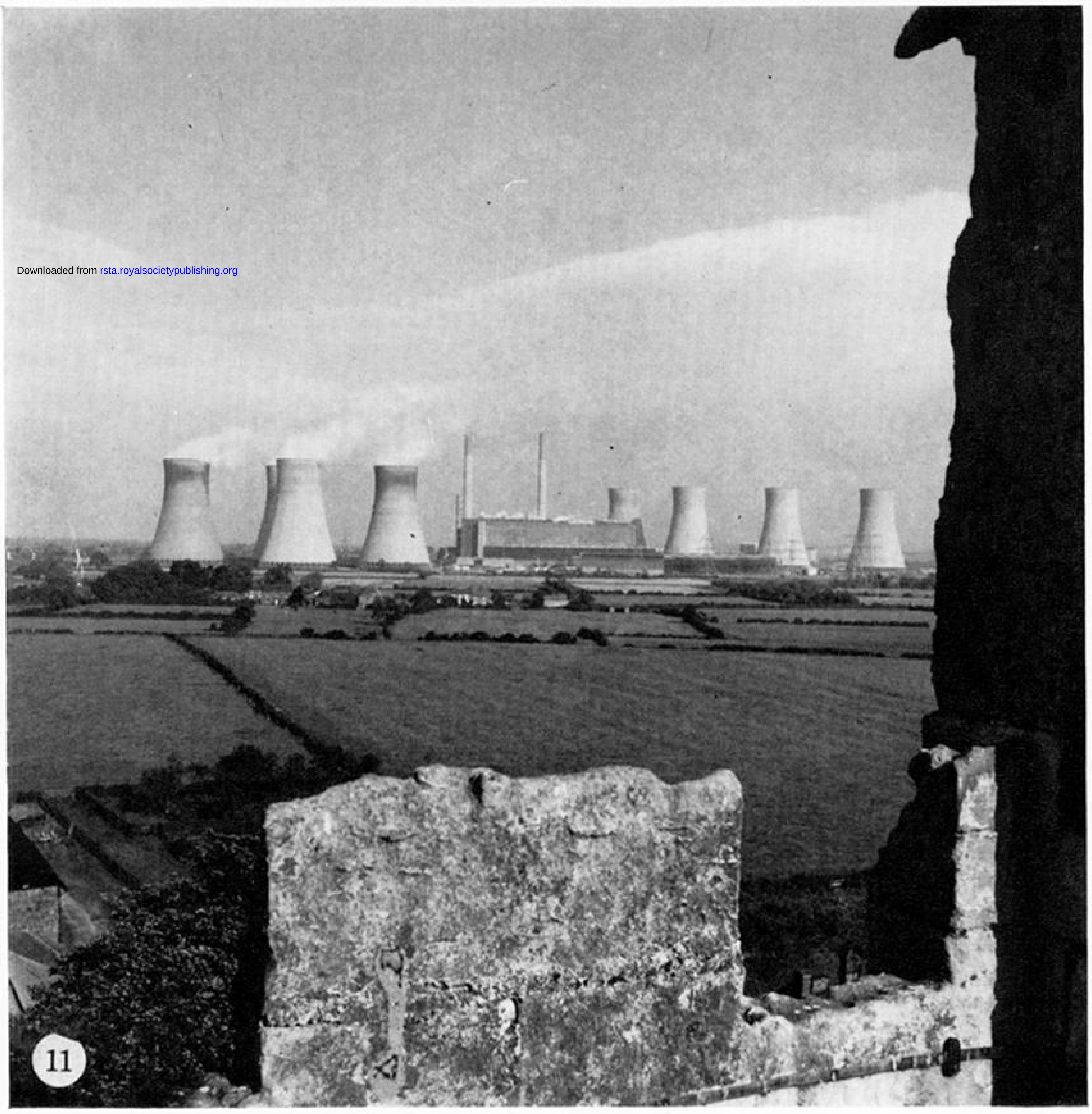

FIGURE 10. Sizewell nuclear power station.

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