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Future Trends in Utilization of Coal Energy Conversion

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ENERGY CONVERSION TECHNOLOGY IN WESTERN EUROPE

Future trends in utilization of coal energy conversion

By L. Grainger
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World reserves of fossil fuels are sufficient for many decades of increasing usage. During the next few decades at least, fossil fuels will be much the most important energy source. These fuels should be exploited in a complementary manner.

Coal represents much the largest potential reserve, followed probably by hydrocarbons less easily utilized than those commonly being exploited now. Techniques exist for the conversion of coal into coke and carbons, electricity, gas and substitute oil-feed stock. Improvements in these processes are possible but their large-scale introduction depends on economics.

Where coal burning can meet a requirement (local heat or steam, or electricity generation) fluidized combustion can be the most efficient process; better integration with mining techniques are possible and environmental considerations are favourable.

Fluidized combustion would be a high priority unit in a 'Coalplex' which could have electricity, gas and oil as possible products. The best mix could depend on the value ascribed to the products and this in turn invokes consideration of the overall economics of energy storage, transport and demand flexibility. Looking farther ahead, coal will certainly remain a vital chemical component for various proposed energy systems and will also probably be able to compete as the energy input into conversion schemes.

The technology of coal utilization may also have applications for other fossil fuels.

The world reserves of fossil fuels are sufficient for many decades of increasing usage, but sooner or later exploitable reserves will be insufficient and it will be necessary to adopt conservationist policies. In the case of oil, such policies will begin to be necessary in this decade even taking into account the production of oil from oil shale and tar sands; on the other hand, coal reserves, being perhaps an order of magnitude greater, could support increasing demands at least until the middle of the next century.

When liquid fuels are in short supply, their prices will rise and their use will be confined to those sectors of the market in which their higher prices are justified by their special properties. In practice, this means that liquid fuels become largely confined to transport and the production of chemicals. When the price of liquid fuels is doubled or perhaps trebled relative to coal prices, it will become economic to produce them from coal; this is likely to be the case in the U.S.A. within a few years but will occur later in the U.K. because of the relatively higher costs of coal and the relatively lower costs of oil. A similar relationship will govern the conversion of coal to substitute natural gas.

Until the time when these conversions become economic, the most important outlets for coal in the U.K. will continue to be in the production of iron and steel and in the generation of electricity.

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Iron and steel production

Considerable attention is being paid in various parts of the world to the development of processes for the reduction of iron ore and the production of steel using process routes which avoid the manufacture of metallurgical coke and the consequent dependence upon supplies of coking coal. However, it does not appear that developments in the direct route to steel have kept pace with the continued and rapid improvements which have been made over recent years to the blast-furnace route. Considerable advances have been made in the improvement of coke while reducing the dependence on traditional 'prime' coking coals. Much of this has been achieved by close collaboration between the N.C.B. and the B.S.C. At the same time there have been considerable advances in the operation of the blast furnace itself, in the preparation of the ore before charging, in the use of higher blast temperatures and with the injection of fuel directly into the hearth. There is still scope for improvement – for instance, tailoring more closely the properties of the fuel to the requirements of the furnace. This objective would be greatly assisted by the establishment on a more scientific basis of the way in which the properties of the input fuel affect the overall performance of the blast furnace. There is a real need for a concerted effort on a large scale to obtain these data. There is every confidence that as information is acquired about the technical requirements for blast-furnace coke and their economic implications, the coke-making process can be modified suitably within the constraints of available cokes.

In the longer term, direct reduction processes may become established in particular locations where local conditions are suitable. It is worth pointing out, however, that the amount of energy required in direct reduction processes now under development is very little different from the energy requirement of the blast-furnace route. The introduction of direct reduction may therefore change the form in which energy is supplied and possibly the location of steel-making plant but may not affect the total quantity of energy required to produce steel.

Electricity generation

Fossil fuel will continue through the 1980s to play an important role in electricity generation. New processes being developed will improve the overall efficiency of generation, reduce waste and lend themselves to the introduction of improved methods of environmental protection. However, the current status of solid-fuel stations has sometimes been misunderstood in discussions of fuel policy and it is perhaps desirable to restate this from the coal industry's point of view.

The costs of generating electricity depend strongly upon the load factor at which stations are operated. This is particularly important in the case of stations with high capital costs. Figure 1 shows representative annual costs of operating different types of stations at different load factors. This shows that at very low load factors, gas-turbine systems are economic and at very high load factors nuclear power stations can be economic. Over a very wide range of load factors, however, fossil fuel–steam stations can be cheaper to operate than either gas-turbine or nuclear stations. The lower curve of figure 1 shows how the demand for electricity in a typical year would be built up in an ideal situation from the three types of station.

These calculations are based on the assumption that all the capacity would be new, using cost estimates and accountancy procedures similar to those used in published documents. In

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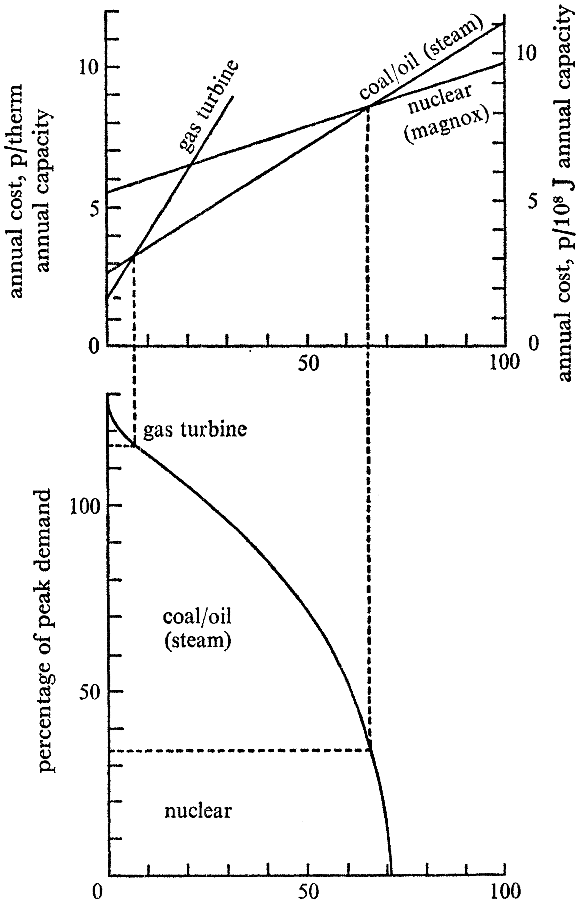

FIGURE 1. Relative future generating costs of electricity.

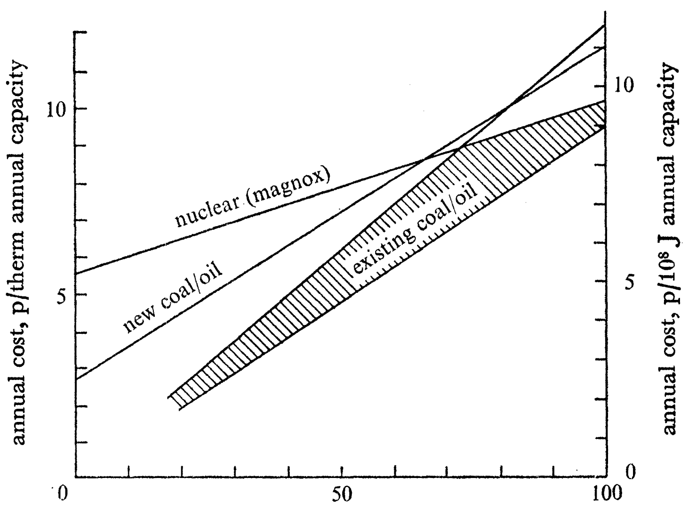

FIGURE 2. Relative future generating costs of electricity.

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practice, the system is built up by adding new stations to those already existing. Figure 2 shows, on similar cost bases, that a new nuclear station would not be competitive with existing fossil fuel stations over a very wide range and would become only marginally competitive at load factors approaching the practical limit of availability.

Two new methods of using coal to generate electricity are under active development – fluidized combustion based largely on pioneering work carried out by the N.C.B., and cycles involving gas turbines based on technology for the gasification of coal.

Fluidized combustion has advantages of high heat release rates, high heat transfer rates and thus reduced equipment costs as compared with conventional systems. Because it is smaller and lighter, construction costs would also be reduced. It can be used in pressurised systems, with further advantages. Coals of high and variable ash content can be used and therefore the amount of energy wasted in a conventional system requiring coal preparation can be reduced.

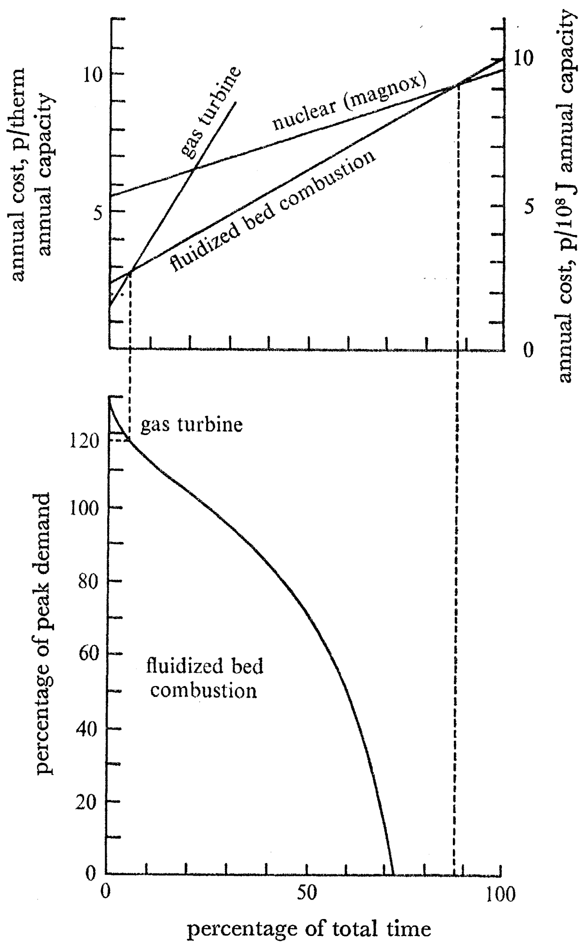

FIGURE 3. Relative future generating costs of electricity.

The system lends itself readily to sulphur absorption techniques. As is shown in figure 3, a fluidized combustion system would be cheaper than published data for nuclear stations at all practical load factors.

In the cycles involving gas turbines, the coal is first reacted with air and steam to produce a low-energy fuel gas from which sulphur can be removed after cooling, by conventional

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techniques. The clean fuel gas is then burnt in a cycle involving gas turbines and steam turbines. Various arrangements of boilers and turbines are possible, but in each case the objective is to reduce the overall capital cost of the station and to increase the proportion of fuel which is converted to electricity. The extent of these improvements depends on the highest temperatures which industrial gas turbines will accept; at present this is about 850 °C but it is expected to rise progressively following the higher temperatures at which aircraft turbines operate.

The progressive improvement in conversion of coal into electricity is illustrated in figure 4 which shows an increasing proportion of the energy in the coal becoming available to the ultimate consumer.

Coal conversion

The changing energy supply situation has added impetus to the development of new techniques for the conversion of coal to gaseous and liquid products. Work on a modest scale has continued for some years in the U.K. at the Coal Research Establishment. In the U.S.A. following the recent Presidential message on energy, the effort on coal research and development has been stepped up to over $100M a year. Pilot plants are being built to demonstrate the viability of improved technology for coal gasification, to make both low-energy gas and substitute natural gas, for coal liquefaction to make hydrocarbon fuels and chemical precursors, as well as for the development of fluidized combustion. Good links have been established with the American work at government and organizational level and our programmes will take full advantage of American experience.

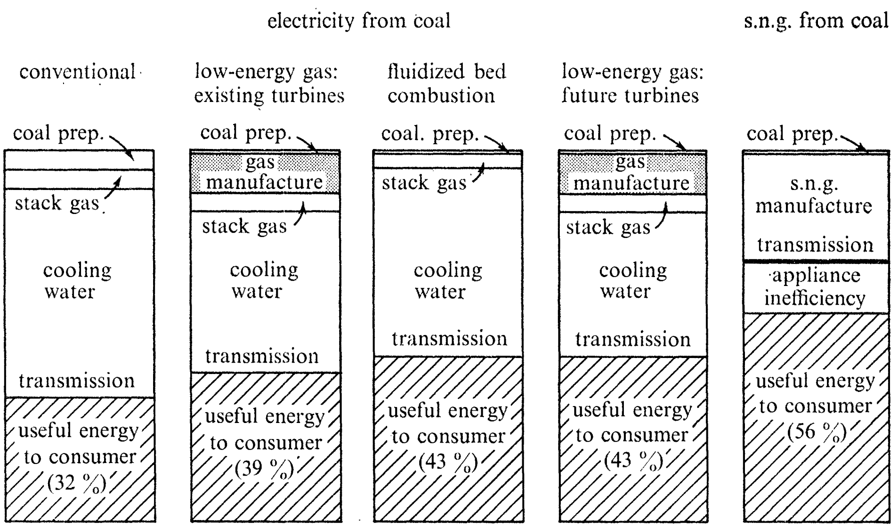

FIGURE 4. Electricity from coal and s.n.g. from coal.

Gasification

Our studies on the economics of the production of substitute natural gas from coal indicate it to be a very much more efficient means of supply of energy from coal than is electricity. The proportion of heat available to the consumer rises to about 56% of the heat originally available in the coal, even after making due allowance for the lower efficiency of the appliance in which it is used. This is illustrated on the right-hand side of figure 4 in comparison with the production of electricity. Figure 5 shows the cost of manufacturing substitute natural gas from

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coal compared with natural gas from the North Sea and the cost of generating electricity at various load factors. It is apparent that from a national resources point of view the separate development of energy supply systems each involving considerable investment in generating and transmission plant, may not be optimal.

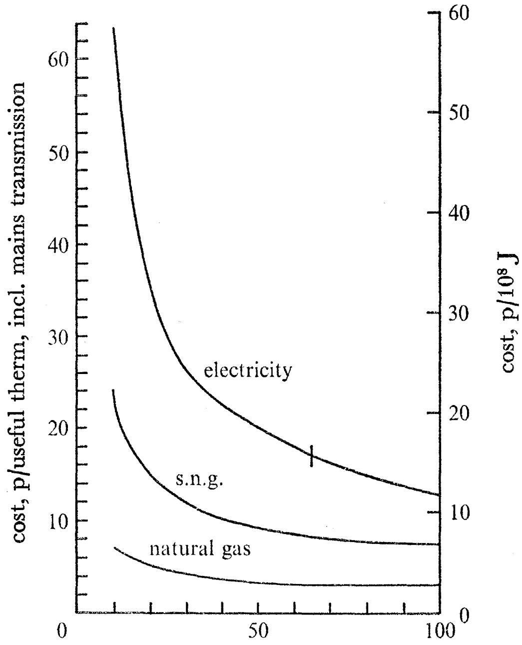

FIGURE 5. Comparative costs of electricity and gas (excluding local distribution).

Coal liquefaction

According to some proponents of nuclear power, the hydrocarbons of the future will be produced by making hydrogen from water by electrolysis and reacting it with carbon dioxide made from limestone. On the contrary, I believe that for a very long time the cheapest source of carbon will continue to be fossil fuel, chiefly coal, and the cheapest way of providing the energy required to convert it into hydrocarbons will be to burn some of it, and the most convenient method of supplying hydrogen will be from the reaction between coal and steam.

This is not to say that existing methods of treating the raw coal are satisfactory; and it is encouraging that increasing impetus is being given, particularly in America, to the development of improved technology. Gasification can itself be used as the first stage of processes for the conversion of coal into a whole range of liquid products including premium fuels and chemicals. The alternative route to liquid products is to attack the coal with solvents. There are basically two variants of the liquefaction process – one uses activated solvents and the other uses hydrogen in the presence of catalysts to break down the coal substance. Instead of using liquid solvents, as in processes being studied in the U.S.A., a new technique is being investigated at the Coal Research Establishment using gases at temperatures and pressures just above their critical point. In this supercritical condition the solvent power is enhanced and solids can be extracted directly into the gas phase and separated from any less-volatile substance which may be present. One advantage of this approach applied to coal is that the problem of separating dissolved coal and mineral matter is considerably eased. It is possible, also, when using supercritical gases, to

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fractionate the coal extract by reducing the temperature in stages; the first fraction being a low-melting solid and the second a viscous liquid at room temperature.

Pyrolysis

In the process of pyrolysis, coal is subjected to mild thermal treatment in the absence of air or steam. There are three products – heavy oils, gas, and char. By careful control of process conditions, particularly the residence time of coal in the system, it is possible to maximize the liquid production at the expense of gas. The char product may be gasified to synthesis gas or burned to provide process heat. The synthesis gas can be purified and catalytically converted to substitute natural gas.

Pyrolysis thus offers a possibility to produce both oil and gas, with an inherent flexibility which permits variation in the proportions of the products. For example, gas production may be maximized by gasifying the oil, or alternatively the synthesis gas may be converted to liquid fuels.

The flexibility of the pyrolysis approach is such that it is desirable to work in this field in addition to work on direct gasification. The N.C.B. is currently working at Leatherhead under contract to the Cogas Development Corporation on specialized aspects of the Cogas process, which involves pyrolysis.

Coalplex

I have demonstrated that there are many exciting new methods under development for the conversion of coal into other forms of energy. We have also been studying ways in which these various unit processes can best be combined together to meet the future energy needs of the U.K. Thus the concept of the coalplex has been evolved. The various unit processes are combined together in ways intended to reduce their overall capital costs and to increase the overall

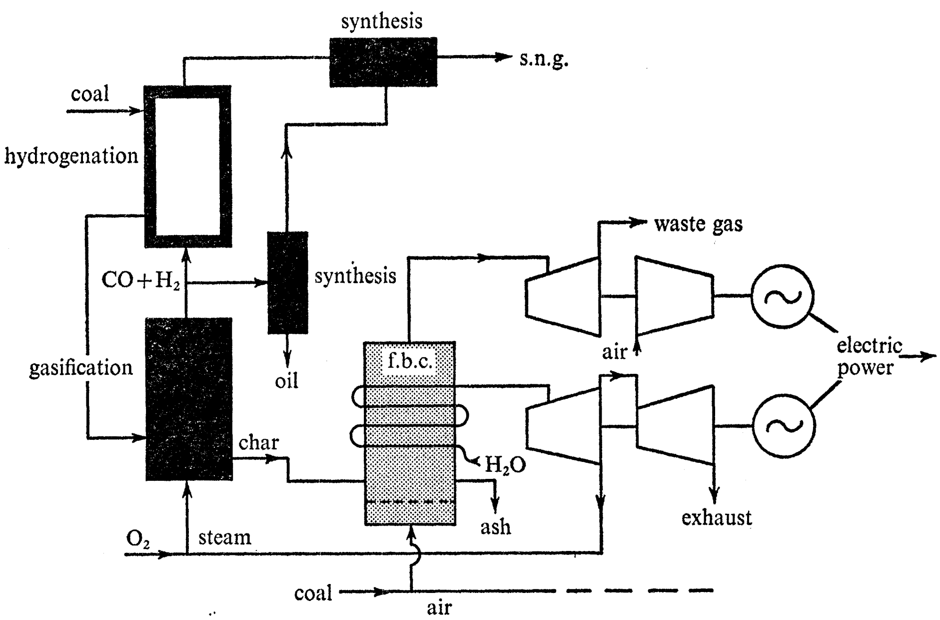

Figure 6. Coalplex incorporating gasification and fluidized combustion.

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efficiency while meeting the needs of the energy and raw materials market, taking account of storage and transport costs.

Figure 6 shows a coalplex incorporating gasification and fluidized combustion. The combustion system uses the char produced from the gasification stage.

Figure 7 shows a coalplex based on liquefaction and fluidized combustion. In this case the residue from the main process is first subjected to partial gasification, the remainder being fed to the combustor.

Figure 8 illustrates the use of liquefaction processes as the first stage in the production of specialized carbon products such as fibres and electrode coke.

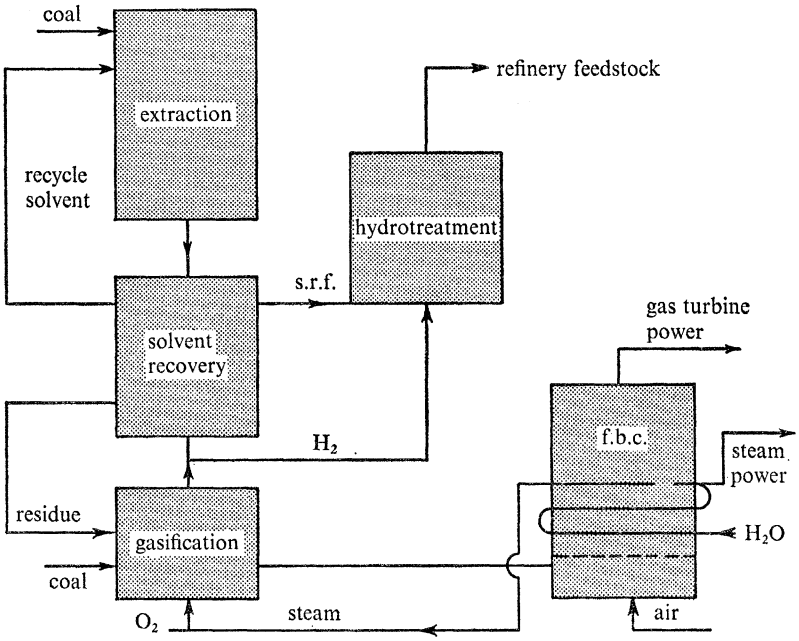

FIGURE 7. Coalplex incorporating liquefaction and fluidized combustion.

ECONOMICS

Various estimates have been published of the cost of producing substitute natural gas in the U.S.A. These have been converted into U.K. equivalents as in table 1, which shows that gas made from coal would cost, at present coal prices, about 6.4p/10^8 J (7p/therm). This is about 3–4 times as expensive as present beach prices, but only about 50 % more than present industrial gas prices. The comparative costs for gas made from oil in table 1 indicate that if oil prices rose by 30–40 % compared with mid-1973 prices, then gas from coal would be competitive with that from oil. In the light of the recent happenings in the Middle East, such rises in oil prices must be expected well before the time when supplies of gas to supplement that from the North Sea are likely to be required.

Similar calculations have been made on the cost of producing substitute crude oil and petrol from coal under U.K. conditions. These indicate that petrol would be produced at about £33/m^3 (15p per U.K. gallon) compared with mid-1973 ex-refinery prices of £13/m^3 (6p per gallon). Thus oil prices would have to double at least, compared with coal, to make petrol from coal economic.

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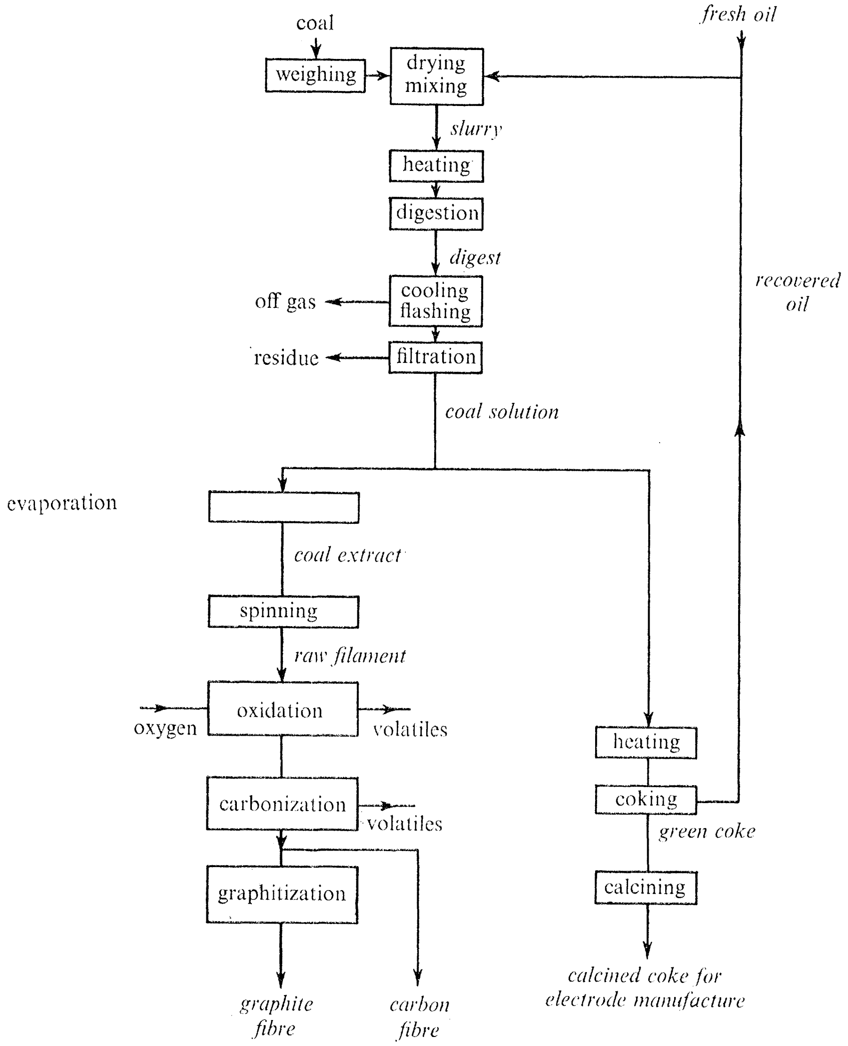

FIGURE 8. Processes for making carbon fibre and calcined coke from coal extract.

TABLE 1. COSTS OF PRODUCING S.N.G. IN THE U.K. – PENCE/10^8 J (PENCE/THERM)

	coal-based system	oil-based system	
	coal at 2.37p/10^8 J (2.5p/therm)	oil at 2.37p/10^8 J (2.5p/therm)	oil at 3.22p/10^8 J (3.4p/therm)
capital related costs	1.6 (1.7)	1.33 (1.4)	1.33 (1.4)
processing costs	1.23 (1.3)	0.95 (1.0)	0.95 (1.0)
raw material (oil or coal)	3.7 (3.9)	3.13 (3.3)	3.26 (4.5)
total	6.5 (6.9)	5.4 (5.7)	6.5 (6.9)
by-product credits	0.19 (0.2)	0.19 (0.2)	0.19 (0.2)
gas costs	6.35 (6.7)	5.2 (5.5)	6.35 (6.7)

Figure 9 compares trends in conventional petrol prices with those associated with the productions of petrol from coal.

Economic studies have been made on plants of the Coalplex type and these show the advantages of combining the various unit processes together. Figure 10 is an example of the result of these studies and shows that by combining an oil-producing plant with gas-producing

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plant, it is possible to show economies. Similar results have been obtained when studying the operation of unit processes together at different load factors. Work continues on investigating various possible ways of improving the advantages to be obtained by combining the unit processes.

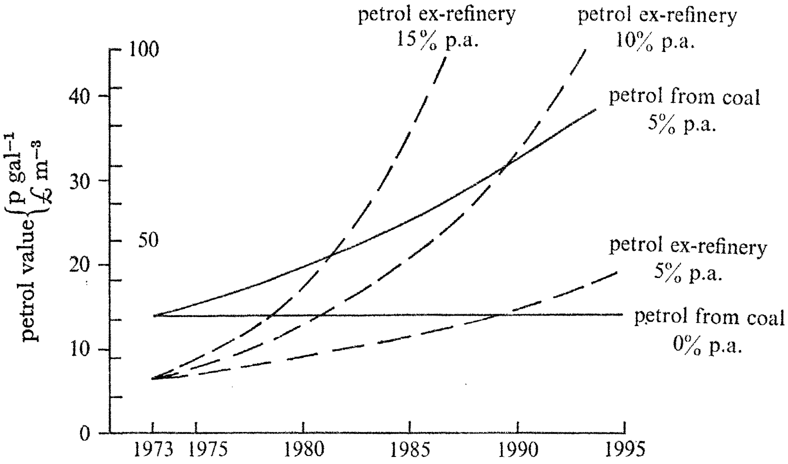

FIGURE 9. Petrol-from-coal processes – effect of cost annual growth rates.

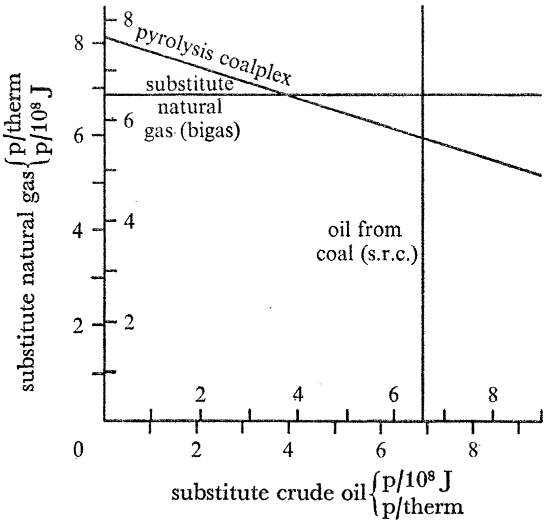

FIGURE 10. Cost advantages of a simple coalplex.

CASE FOR NATIONAL PROGRAMME

The existing research programme at the Coal Research Establishment on the conversion of coal into other forms of energy, while adequate to preserve our familiarity with the technology, needs to be supplemented by operation on pilot plant and on demonstration scales. It is for the latter type of operation that national funds are being sought. An outline of a development programme is shown in table 2. This caters for investment in demonstration and plant-scale operation over a 5-year period. The order in which investment will be made corresponds broadly with that in which the opportunities for coal are likely to arise. Thus the first plant would be concerned with demonstrating fluidized combustion on a 20 MW scale, and would come into operation in 1976.

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There would also be a liquefaction unit which would be commissioned early in 1977 to make coal extract freed from mineral matter and suitable for hydrogenation to liquid products. This unit could make the raw material for a special carbons plant.

In 1977 work could also start on the construction of a pilot gasification unit, based on laboratory studies in the preceding three years. The first objective would be to demonstrate an improved process for making low-energy gas. This plant could be integrated with the fluidized combustion unit and would later be used for work on the production of synthesis gas for substitute natural gas and/or hydrogen.

Table 2. Proposed national programme of coal processing research

	£10^6				
	1974/75	1975/76	1976/77	1977/78	1978/79
fluidized combustion unit, 20 MW					
design and specification	0.5	—	—	—	—
construction	0.5	2.0	—	—	—
operation	—	—	0.5	0.5	0.5
demonstration liquefaction unit					
design	0.25	—	—	—	—
construction	—	2.0	1.0	—	—
operation	—	—	0.5	0.5	0.5
gasification unit, s.n.g. low-energy hydrogen					
design	0.2†	0.2†	0.2†	—	—
construction	—	—	—	1.0	1.0
operation	—	—	—	—	0.5
pyrolysis unit					
design, construction	0.5	0.5	—	—	—
operation	—	—	0.5	0.5	0.5
analytical studies	0.1	0.1	0.1	0.1	0.1
metallurgical fuels					
special fuel production and testing	0.1	0.2	0.3	0.3	0.3
plant construction	—	—	—	1.0	1.0
total coal processing programme	2.15	5.0	3.1	3.9	4.4

† Programme at C.R.E. supported by E.C.S.C. funds.

The outcome of the present studies of the various pyrolysis systems will be to identify an optimized process which will require demonstration on a reasonable scale. It is proposed that provision should be made for a pilot pyrolysis unit which might be built and operated in 1976/77.

In addition to these plants demonstrating processes for the conversion of coal, it is suggested that it is in the national interest to provide funds for a national programme on the production and testing of special metallurgical fuels, the programme to include large-scale blast furnace trials, and construction of a formed coke demonstration plant.

The overall programme is aimed at the acquisition of know-how in the operation of hardware at the earliest possible time. This will involve a degree of telescoping of the conventional planning of research and development, but the exigence of the situation make it necessary.

The views expressed in this paper are those of the author and not necessarily those of the National Coal Board.

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Discussion

Dr I. Fells (*Department of Chemical Engineering, University of Newcastle upon Tyne*)

Designs for power stations of up to 500 MW based upon fluidized bed combustion of coal were presented some five years ago. It is a pity that at least the 30 MW station proposed then is not under construction now. The lead time for construction of the various plants you have proposed is probably five years at least and it is disappointing that in this country the proposals you have put today still await financial support whilst work is already underway on similar projects in the United States.

The suggestion that we should build demonstration plant is surely not ambitious enough. Problems always arise when scaling up to operational units. We need to build prototype plant for proper economic and engineering evaluation.

Sir Kenneth Hutchinson (46–47 *Pall Mall, London S.W.* 1)

A new future has opened up for coal as a raw material for production of refined fuels, and the pioneer work of the late Dr F. J. Dent on coal gasification should now be reconsidered. This work was suspended at a time when the gas industry was forced by market considerations to base its future plans on the manufacture of gas from naphtha, which had become readily available and cheap in the 1960s. The discovery of North Sea gas confirmed this decision. However, we have just seen the United States passing through the era of plenty and heading rapidly for a shortage of oil and gas, not only in this period of political uncertainty but in the long term also.

Dent's most significant discovery was when he showed that methane is synthesized under the conditions of pressure gasification of coal in steam and oxygen, and a hydrogasification stage has been incorporated in the I.G.T. complex in Chicago.

One technological advance in a related field which may prove to be just as significant was the successful operation of a slagging gasifier of the Lurgi type. A pilot unit was brought over from Germany by the Ministry of Power and installed by the Gas Council at their Midland Research Station at Solihull. After complete rebuilding it was shown to be capable of operating without insuperable difficulties at a pressure of 3 MPa, and of outputs of up to four times those of the conventional type. The ash was extracted from the reaction zone in liquid form and quenched in water to give an easily managed frit. In normal Lurgi practice it is essential for the ash to be in a coherent but not in a fused form, and the large volumes of steam which have to be used to keep the ash cool slow up the process, and reduce efficiency.

Meanwhile the Fischer Tropsch process for synthesis of liquid fuel from coal had been studied first at the Fuel Research Station at East Greenwich, and later in an improved form at Warren Spring. Design studies for a coal complex were presented to the Committee on Coal Derivatives (The Wilson Committee) in 1959, but no further development could be recommended at that time, when oil products were so cheap and plentiful. In discussion with Mr Brian Locke the Project Director of N.R.D.C. it seemed to us that a combination of the slagging gasifier as operated at Solihull with the improved Fischer Tropsch synthesis using a slurried catalyst could provide a sound basis for further development. With some further modification it might be possible to produce liquid and gas in about equal proportions, and for both of these there exist almost unlimited markets at high prices. The efficiency of a process designed to

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produce both liquids and gas could be better than that of processes which produce only one or the other, and there is of course a wide range of options in between.

The pilot plant at Solihull has been demolished and the Lurgi plant at Westfield in Scotland, the last of its kind in Western Europe, seems likely to shut down next year after completing some tests on methane synthesis for American interests. Before a final decision is taken, the possibility that I have outlined might be brought to the attention of those who have already shown interest in the conventional Lurgi process, and have supported further experimental work at Westfield. The slagging gasifier is likely to work best with coals having a low fusion point ash and might be very attractive to certain parts of the United States.

The process outlined here is hardly likely to find application in the United Kingdom in the near future. But if much larger reserves of coal become available than can now be foreseen, or if coal is found at more accessible depths in the North Sea it will be of the greatest value to have experience of a viable process available to us at about the turn of the century. And, in the meantime we might find in this work a valuable outlet for British based technology of a high order.

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