Oil and coal: reserves and production

Anton Ziolkowski*

The 1984–85 strike by British coal miners has focused attention on the difficulties of the coal industry at a time when demand for energy is slack and oil prices are falling. The coal industry does not look very glamorous. Do we really need the coal? In this article it is argued that in the foreseeable future we will become increasingly dependent on coal. This is mainly because the rate of discovery of new oil reserves is insufficient to sustain our current dependence on oil.

Historical background

At the end of 1973 the era of cheap oil came to an end. The growth in the prosperity of the western industrial countries had depended on the importation of this cheap oil to the extent that the growth in the demand for oil was more than twice that of all other sources of energy put together (Fig. 1). Some countries, particularly Japan and those in Western Europe, had based their growth almost entirely on oil (Fig. 2). The United States, one of the world's largest producers of oil, had also become the world's largest importer of oil and, by 1973, was importing about 6 million barrels per day (mbd) (Fig. 3)—equal to about 11% of the world oil production. Consumption of oil in the United States was equal to 28% of world oil production. That is, 6% of the world's population was consuming 28% of all the oil produced. Western industrial countries had attributed their growth to their industrial efficiency, but, as Schumacher (1973) pointed out, the efficiency with which the western industrial countries were expanding their economies depended on an extremely inefficient use of the world's non-renewable resources.

From October 1973 to January 1974 the export price of crude oil from the Organisation of Petroleum Exporting Countries (OPEC) quadrupled (Fig. 4). There were many political factors in this price increase, of course; but there was also the underlying inescapable fact that the rate of discovery of new oil reserves was not keeping up with the rate of increase of oil consumption. Demand was doubling every 12 years, but new discoveries were not adding to known oil reserves at the same rate. The rate of increase of demand was greater than the sustainable rate of increase of supply, and the price was bound to go up sooner or later.

*Department of Mining Engineering, Technische Hogeschool Delft, PO Box 5028, 2600 GA Delft, The Netherlands.
After the oil price shock of 1973–74 many studies on the future production of oil were undertaken, especially in the industrial nations of the Organisation of Economic Cooperation and Development (OECD) which relied on oil for more than one-half their total energy needs. The situation was described in the famous projection by the Workshop on Alternative Energy Strategies (WAES, 1977), shown in Fig. 5. The essential feature of the oil production curve is the peak before the year 2000. If the peak were to be reached early, say by 1980, the supply could be maintained at an almost constant level for about another 20 years. If the increase in production were to be sustained to keep pace with demand until, say, 1990, there must follow a very rapid decline in production. In either case, by the year 2000 there would be a world ‘energy gap’ amounting to about 25 million barrels of oil a day. If this gap is not filled by some alternative source of energy, there will be a rapid decline in the standard of living all over the world—

unless the world learns to use energy more efficiently than it has done to date.

While the world was glorying in the almost unlimited supply of cheap oil (and gas), the coal industry was having a difficult time. The technological advances that were taking place in the methods of extraction and combustion of coal hardly ever made the newspaper headlines. Headline news about coal was more often about miners’ strikes than about new methods of mining.

The main markets for coal were:
1. the generation of electricity in coal-fired power stations;
2. to produce coke for metallurgical purposes;
3. as an industrial fuel;
4. as a domestic heating fuel.

The only one of these markets which has really not been affected by oil is the coking coal market, which is subject to the competition between different suppliers of coking coal throughout the world. The price of coal in the other markets has been determined worldwide almost entirely by the price of oil. In the domestic fuel market, coal has now become completely eclipsed by oil and gas which are generally cheaper and much more easy to use. In the industrial market coal’s share has been reduced to about 10% worldwide, while in the electric power market coal competes directly with oil and gas, its share of the market varying from country to country and depending on various factors including the relative availability of other sources of energy (such as hydroelectric power) and on government policies.

As oil became steadily cheaper, in real terms, until the beginning of the 1970s, the real price of coal was driven down too. This had a dramatic effect on the ‘technically and economically recoverable’ reserves of coal (Fig. 6). In 1973, only 2.5% of all the physically recoverable UK coal reserves were regarded as economically recoverable (Clarke, 1976). Had the oil crisis of 1973–74 been averted for, say, another five or six years, the economically recoverable reserves of Britain might have been assessed at zero. The last coal mine in the Netherlands was closed in 1973; France produces less and less coal each year; and the Belgian coal industry has practically vanished. The point is, that cheap oil very nearly caused the closure of all the coal mines in Western Europe.

Thus, while the oil industry was expanding so fast, the coal industry was struggling to survive with ever-decreasing reserves of economically-recoverable coal. The oil industry was clearly more attractive to investors that the coal industry, which was badly in need of modernisation. Of course this modernisation could not take place without the investment. The principal argument used to justify government investment in the coal industry in Western Europe was that the cheap oil was bound to run out one day, and since there were no significant oil reserves in Western Europe, it would have
to depend on a healthy coal industry. This argument did not always succeed, of course, because nuclear power has always looked modern and attractive, especially to the electric power industry, the biggest user of coal, which never wants to be at the mercy of striking coal miners.

In France, the nuclear lobby has won and the coal industry is dying a slow death, starved of capital. In the Netherlands, the deep coal in thin seams could not compete with the enormous reserves of natural gas in the Groningen natural gas field. In the Federal Republic of Germany there has been sustained investment in coal. In Britain successive governments have hedged their bets between nuclear power and coal, and then found they also had North Sea oil and gas. In the United States there are vast reserves of thick shallow coal which are less costly to extract than the deep coal of western Europe; but the deeper, older coal mines of the Appalachians suffered from cheap oil much as the coal industry of western Europe had done.

**Bridging the energy gap**

In 1980 the World Coal Study (WOCOL) published its Final Report (Wilson 1980) after 18 months of intensive work examining the role that coal might play in meeting the world energy needs until the end of the century. It involved 80 participants from 16 major coal-using and coal-producing countries. When WOCOL began its work in 1978, the world supply of energy was equivalent to an oil production of 126 million barrels per day (mbd), of which oil contributed 63 mbd, or as much as all other supplies of energy put together (Fig. 7). Coal production was 2500 million tonnes per year or equivalent to 33 mbd. In order to bridge the projected 'energy gap' shown in Fig. 5, the non-oil supplies of energy had to be rapidly expanded.

If nuclear power had to fill the gap, it would need to expand 10-15 times within 25 years. Such expansion looked very unlikely in 1978 and looks even more unlikely today, given the present uncertainties about the safe disposal of nuclear waste, and widespread public distrust of existing nuclear power stations. The reserves-to-production ratio of gas is greater than for oil, but the largest known reserves are in the Soviet Union and the OPEC countries, and it is unlikely that OECD countries could rely on steady expansion of these supplies to meet their demands.

WOCOL began its work with the understanding that world energy needs could not rely on energy conservation and expansion of nuclear power, gas production, solar energy and other renewable resources. Coal had to be looked at again.
WOCOL concluded that coal would have to supply between one-half and two-thirds of the additional energy needed by the world during the next 20 years and, to do this, coal production would have to increase 2.5 to 3 times. For this expansion to take place, it would be necessary for many individual decisions to be made along the chain from coal producer to consumer to ensure that the required amounts would be available when needed.

The limitations on the necessary coal expansion are not the reserves, or the technology (which exists), or the financial capital, but a coordination of many different individuals. Delays at any point affect the entire chain.

Developments since 1973
For five years after the quadrupling of oil prices in 1973–74 the price of oil remained very steady, and in real terms actually declined (Fig. 8). In some respects the price rise was absorbed. It did not lead to overnight changes in the pattern of energy use, partly because such changes take time, and partly because it was not recognised for several years by the great majority of consumers that the price rise was inevitable and not purely the result of the OPEC cartel exercising its muscles.

The coal industry had been forecasting oil shortages and increased prices for years. One of the clearest prophets of the inevitability of oil shortages and high oil prices was E.F. Schumacher, Chief Economic Adviser to the National Coal Board, who had for years been warning the world of the problems of increasing dependence on non-renewable resources, especially oil. In 1973 his famous book Small is beautiful was published—before the enormous oil price rises. He fully expected the price increases and their effects (Schumacher 1973). His argument (p. 110) was that demand for oil was so inelastic that OPEC could raise their revenues simply by curtailing output. For five years the pattern of energy consumption did not change significantly. Then, in 1978, there was a revolution in Iran. Oil exports from Iran, previously 5 mbd, were suspended from 27 December 1978 to 4 March 1979 before being resumed at a reduced rate of about 2–3 mbd. This reduction was partially offset by increased oil production and exports by Saudi Arabia and Kuwait, but its effect on the price was exactly as Schumacher had forecast (Fig. 8). At about the same time many big energy studies (such as WAES) were reaching the conclusions that Schumacher had reached years before. By 1980, with the price of oil 15 times what it had been a decade earlier, or 10 times greater in real terms, the world was beginning to adjust to the realisation that dependence on oil was too great.

Oil production and reserves
Table 1 gives estimates of oil production in mbd and proved oil reserves, technically recoverable at current prices, for the period 1974–84. Probable and possible oil reserves are not included. The figures are from the ‘Worldwide Reports’ published by Oil and Gas Journal. Also included are the annual production figures (bbl/day

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<th>Date</th>
<th>Estimated proved reserves (10^9 bbl)</th>
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<th>Production (10^9 bbl/year) (years)</th>
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and the reserves to annual production ratio in years. Figure 9 shows the same data in graphical form.

There are many striking conclusions one can draw from these data; I shall point out only a few. First, the production curve, Fig. 9(b) looks very similar to the WAES projected production curve based on a 33 mbd OPEC limit. There is no effective OPEC limit at present, but there is a lack of demand mainly because of worldwide recession. Secondly, the reserves curve is very flat. This is very significant. There has been an enormous increase in the price of oil, and there have been great advances in the technology of exploration for oil; but the reserves curve is flat. This suggests that the quantity of known technically and economically recoverable reserves of oil is insensitive to improvements in technology or increases in price. This is in stark contrast to the effect of price on the economically recoverable reserves of coal (Fig. 6). Thirdly, the reserves to production ratio is about 30 years, but appears to be increasing mainly because production—which is at present limited by demand—has been decreasing. It is clear that the rate of discovery of new oil reserves has been much less than the 5.7% per year increase in oil consumption which took place in the 1960s and early 1970s (Fig. 1). The current reduction in demand for oil has bought us a little time.

The reduction in demand for oil has not been caused by any major shift to alternative sources of energy. It has been caused partly by slightly more efficient use of energy, particularly in the United States, and partly by recession. The recession is exactly what was predicted by the WAES projection of Fig. 5.

Many goods and services depend directly on oil. When the price of oil increases, these goods and services become more expensive. The principal effects of the oil price rises of the 1970s were two-fold. First of all they were inflationary, pushing up the price of almost everything. Secondly, they were like a huge tax on the world without much direct benefit. In real terms the world was paying 10 times as much per barrel of oil in 1980 as it paid in 1970, and was producing very little more per barrel. The tax was paid by reducing expenditure on other goods and services. That is, the oil price increases enforced reduced demand on other goods and services which caused recession all over the world. The widespread recession has reduced the demand for energy—including oil—and the real price of oil has come down.

Incidentally, the increase in oil revenues has been so great that it has been impossible to put all this extra money to good use. The result has been an enormous strain on the international banking system which has been unable to find a sufficient number of worthy projects which will yield a return on the investment. There is consequently now a huge quantity of 'hot' money in the system which is being switched unpredictably from currency to currency, chasing high interest rates and low inflation in an effort to avoid losing value. This is causing extreme volatility in financial markets and making forward planning in many industries very difficult.

The expected resurgence of coal has not come. The reason is that the world, especially the OECD countries, is still very dependent on oil. Oil is not so expensive now (1984) because there is a lack of demand. Demand is low because there is a recession. The recession was caused by high oil prices. When the recession is over, demand for oil will increase, the price will rise and the underlying problem of the small reserves-to-production ratio of oil will determine the rate of growth—unless coal bridges the energy gap.

### Coal production and reserves

Attempts by the coal industry to bridge the gap have not been going smoothly. In Britain, for example, the National Coal Board responded to the oil price rises of 1973-74 and to their rapidly diminishing reserves of economically recoverable oil (Fig. 6) with Plan for Coal (1974). This was a plan for rapid expansion of coal production based on a programme of modernisation and expansion of existing mines as well as exploration for new sites and development of new coal mines. The Plan for Coal was an agreement between the National Coal Board (NCB), the National Union of Mineworkers (NUM) and the Government of the day. The agreement

*The corresponding reserves to production ratio for the United States is only nine years.*
followed a miners' strike which had brought down the previous government.*

Plan for Coal was based on the assumption that Britain's energy needs would increase by about 30% in 10 years. In fact, because of deep recession, Britain's energy demand is about 15% less than it was in 1973 (The Times, 11 July 1984, p. 2). The expansion in coal production capacity has been taking place, coal has been produced, but it cannot all be sold because there is not enough demand. The miners who have mined the coal have been paid, but the coal sits around in piles, unsold. There is no return on investment made for the expansion, and meanwhile unemployment has rocketed, and the government cannot sustain the long-term investment plans because it considers the enormous short-term problems to be of overriding importance.

One way of looking at all this is that the dependence on oil is still too great. Now that there is a very deep recession it is difficult to finance the shift in dependence from oil towards coal. If the shift had been more smooth, and had it taken place earlier, perhaps the dramatic oil price increases of the 1970s could have been absorbed without such shocks to the economy. This smooth shift would not have taken place without coordination between potential coal users and coal producers. This coordination has not taken place.

The potential of the coal industry to provide sufficient energy for the foreseeable future should not be in doubt, although the study and assessment of coal reserves is a very complicated and difficult subject on which there is no worldwide agreement.

In order to be able to compare reserves of one kind of coal with another, the calorific value of the coal must be taken into account. There is now a standard for comparison, based on a calorific value of 28 MJ kg−1. The comparison is made on the basis of the quantity of coal required to have the same heat value as a tonne of coal with this calorific value—1 metric tonne of coal equivalent (tce).

In principle the calculation of 'coal in place' is simple. It is the product of seam thickness, area of the seam and density, summed over all the coal seams. The accuracy of the calculation depends on the estimates of the average thickness of the seams and their lateral extents. These are usually known less accurately than either the density or the calorific value. In making the calculation, there is a maximum depth that is considered, as well as a minimum seam thickness. In general 'hard coal' seams deeper than 2000 m are not counted, while 'brown' coal seams deeper than 1500 m are not counted, according to WEC specifications. There are no WEC specifications on the minimum thickness of seam which should be included in the calculation. The total known coal-in-place worldwide calculated according to WEC specifications, is 10750212 mtce (million tce).

The technology of mining determines the fraction of coal in place that is technically recoverable. Only a certain fraction of this technically recoverable fraction is economically recoverable, but there is an enormous problem in deciding how to define what is 'economically recoverable' on a worldwide basis. The fraction of a certain nation's coal reserves that is considered economically recoverable depends, for example, on whether there are alternative supplies of energy available and on the prices of these supplies.

Table 2 gives the WOCOL estimates of the technically and economically recoverable reserves of coal, based on WEC figures and updated by WOCOL countries (Wilson 1980). The table shows enormous variations from country to country in the fraction of coal in place which is considered both technically and economically recoverable, and reflects the disagreement there is about how one defines what is economically recoverable.

The way in which each country calculates its own technically and economically recoverable reserves of coal varies from country to country. In one country the technically and economically recoverable reserves may simply be the sum of the better than break-even risks estimated for each existing coal mine, based on current economic conditions and determined to a great extent by the current price of oil. In another country, the fraction of coal in place that is technically recoverable using today's technology may be used as the fraction that is regarded as technically and economically recoverable, on the ground that the present influence of the price of

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*The miners had been on strike for 20% more pay to meet loss of earnings caused by inflation, when the quadrupling in oil prices occurred. Salaries and wages are about 55% of the costs of producing coal in Britain, so the wage increase would have raised the price of coal by about 11%. The government was ready to pay 300% more for the imported oil (with dollars that had to be earned by exports), but was not ready to allow the NCB to charge 11% more for coal which, even before the oil price rise, was being produced at a price competitive with oil.
oil is essentially a short-term factor which will not greatly influence the long-term future of the coal industry in that country.

The National Coal Board is the body responsible for producing Britain's coal which, to a large extent, still drives the economy. (Britain's coal production is about 100 mt yr\(^{-1}\), which has the same calorific value as an oil production of 1.3 mbd.) The NCB must therefore be a viable business. At the same time, the NCB is also trustee of the nation’s coal reserves and should ensure that the long-term future of the coal industry is not jeopardised by short-term considerations. The problem is that current short-term problems demand solutions which are very likely to reduce economic prosperity in the longer term.

When a mine is closed, the maintenance of the structures necessary to keep the roof and floor apart is discontinued. The pumps, which remove the large quantities of water which pour into nearly every coal mine, are turned off. In a few years the mine fills up with water and the roadways collapse. It is then impossible to reopen the mine and the coal reserves which were accessed by the mine are sterilised. To keep the mine open without working the coal is a significant fraction of the cost of mining, but it produces no coal. In other words, it is very expensive.

Thus the short-term benefit of closing mines that are unprofitable at today’s prices is to cut losses, or to minimise current costs. The long-term costs of obtaining this benefit are the reduction of coal production capacity and the sterilisation of coal reserves.

**Conclusion**

The underlying situation is this. If the world economy must expand, it must reduce its dependence on oil and must, for the foreseeable future, rely more on coal. Coal production must increase by about 2 or 3 times by the end of the century, and methods must be developed to make production less costly.

The economic growth of the 1960s and early 1970s was based on expansion of oil production and was choked off by the oil price rises of the 1970s, because there was no readily available alternative source of energy. The evidence of the last 10 years is that large increases in the price of oil and improvements in the technology of exploration make only small increases in the known recoverable reserves of oil. At the present low worldwide oil production rate of 54 mbd, the reserves-to-production ratio of oil is only 35 years. There is thus every reason to expect that economic growth based on expansion of oil production will be rapidly choked off by the limited reserves of oil.

The known technically and economically recoverable reserves of coal are currently 6% of the known reserves of coal-in-place, and exceed the technically and economically recoverable reserves of oil by about an order of magnitude. Furthermore, the fraction of coal in place which is technically and economically recoverable is historically very sensitive to changes in the price of coal. Therefore, in the long term, coal should have a very bright future.

This future, and consequently our future economic prosperity, would be made less bright by the closure of coal mines and the sterilisation of the reserves to which they now have access.

Received 7 February 1985; accepted 20 March 1985.

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The Times. 11 July 1984.


*In the long run the present technological necessity for continued expansion of production leads to insuperable problems—including the rapid depletion of non-renewable resources. In the long run, therefore, the technological basis for economic survival must change radically.