COAL IN RELATION TO ATMOSPHERIC POLLUTION*

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IN 1912, following an international smoke abatement exhibition in London, there was appointed an Advisory Committee on Atmospheric Pollution under the Meteorological Office. Later, in 1927, the work of this Committee was taken over by the Department of Scientific and Industrial Research. Under the guidance of the Atmospheric Pollution Research Committee of the Department, and with the co-operation of many local authorities, methods of measurement of different forms of atmospheric pollution have been improved and new methods devised, and systematic records of the extent of pollution in many parts of Britain have been obtained. The results of this useful work have been published in a number of annual reports of the Committee. Over a period of three years just before the War, an intensive survey of atmospheric pollution in Leicester was undertaken under the guidance of the Research Committee and a full report of this work is now in the press.

There is no doubt that all these activities have played their part in bringing about during the last fifty years a gradual but very definite improvement in many areas. There is much truth in the statement that the old type of London fog is now almost unknown. Much still remains to be done, however, before the air of our towns will be reasonably clean and free from smoke and other forms of pollution; and the ultimate goal will not be achieved except on the basis of intensive scientific research in several directions.

Quantity of Coal Used in Relation to Population

Before discussing the nature and the quantity of the polluting substances discharged into the atmosphere from the use of coal for different purposes, let us consider what changes have occurred in Great Britain since the beginning of the eighteenth century in the rate of production of coal, and in the relationship between the rate of production and the size of the population. This period is chosen because it was during the eighteenth century that there were the first signs of the beginning of the enormous developments in the use of coal which took place in the nineteenth century, particularly in the second half of that century. Great Britain has been fortunate in possessing reserves of coal of good quality and of many types. Early recognition of the possibilities in the use of coal for the generation of heat, power, and light, and the skill and enterprise of our scientific men, engineers and industrialists of 100-150 years ago, gave Great Britain a good lead in the industrial developments that followed.

The rapid rise in the use of coal was accompanied by a marked increase in the population. The great changes which occurred are indicated by the accompanying curves, which are plotted from estimates of the population and of the annual outputs of coal from the year 1700 to the early years of the present century.

* Substance of a Chadwick Public Lecture delivered on March 13.

The important changes in Great Britain during the last 140 years have thus included an increase in the annual output of coal from roughly 10 million tons to about 200 million tons, and a great increase in the population from roughly 10 to 45 millions, and the crowding of masses of people in large towns. Most of the coal brought to the surface in Great Britain is used in this country. If there had not been considerable improvements in the methods of using coal, atmospheric pollution from this source would certainly have been very much worse than it is to-day.

Efficiency of Use of Coal

In Table 1, figures are given to show the principal inland uses of coal in Great Britain and the quantities in millions of tons a year for the three-year period 1936-38.

TABLE 1. SOME USES OF COAL IN GREAT BRITAIN (ANNUAL AVERAGES FOR 1936-38).

	Purpose for which coal is used	Quantity in millions of tons
1	General use, including 40-45 million tons for domestic purposes	98
2	Electricity power stations	14
3	Coke ovens	20
4	Gas works	19
5	Railway locomotives	13
6	Collieries	12
7	Ships' bunkers, foreign and coastal	12
	Total	188

With what efficiency is the coal used for the various purposes mentioned above, and can the efficiency be increased? Unfortunately it is not possible from available data to do more than give very rough estimates of the efficiency of utilization of coal for the many purposes for which it is employed. The rough estimates that can be made, however, do serve as a useful guide.

Of the quantity of 98 million tons given in the first item of Table 1, approximately 40 million tons is used for domestic heating and cooking and 60 million tons by various industrial undertakings for such purposes as heating furnaces and raising steam for processes and for power. Though the efficiency of generation of steam in large boiler installations of the most modern type is often as high as 80 per cent, this high efficiency cannot be maintained unless the

equipment is kept in first-class condition and is operated under close scientific supervision. In the past, coal has been relatively cheap, and in large numbers of industrial undertakings little attention has been given to equipment such as boilers and furnaces. Far too much heat, which could have been usefully employed in several ways, has been carried away in hot gases and liquids, and large quantities of steam have been wasted. With many furnaces of the kind used for heating metals, not more than 4-5 per cent of the heat value of the coal is put to useful purpose. It is difficult in furnaces of this kind to obtain high efficiency, but there is no doubt that appreciable improvement is practicable in many cases. As an overall figure, it is unlikely that the efficiency of use of the 60 million tons of coal included in the first item of Table 1 for industrial purposes exceeds 50 per cent.

On the domestic side, the overall efficiency of the open coal-fire under average household conditions is not more than about 20 per cent. The corresponding figure for the general purpose appliance in which coal is used for space heating, provision of hot water, and cooking is somewhat greater because of the heat taken up by the water, but it is probably not more than 25 per cent. Here is considerable room for improvement. Much effort is now being expended in designing open fires to provide not only radiant heat, but also convected heat derived from air which is heated by passage through ducts adjacent to the fire; the warm air is discharged into the room in which the fire is placed, or into other rooms. The probability is that with systems of this kind the average householder would obtain an efficiency of 30 per cent in place of 20 per cent with the ordinary open fire.

During the past twenty-five years there has been great expansion in the use of electricity and a great increase in the efficiency of generation. The quantity of coal consumed annually during 1936-38 at electricity power stations was 14 million tons; this is more than twice as much as during the years 1921-23, and in 1943 the amount was about 23 million tons. In 1921 the average quantity of coal consumed to produce one unit of electricity was 3.4 lb., whereas in 1938 it was only 1.4 lb. This means that the efficiency of generation was two and a half times as great in 1938 as in 1921. Even with this great improvement, the heat equivalent of the electricity generated was only about 20 per cent of the heat value of the coal burned under the boilers. Allowing for losses in transmission, the efficiency of generation and distribution in 1938 was about 18 per cent. Though the efficiency of generation is low the efficiency of utilization is usually high; for example, it may be taken as practically 100 per cent for the electric fire; this means an efficiency in relation to coal used at the generating station of 18 per cent.

Before the War the efficiency of carbonization of coal in coke ovens and at gas works had reached the high average of roughly 75 per cent. Further improvement is probable but it clearly cannot be very great. From each ton of coal carbonized there is produced about 14 cwt. of coke, 60-80 therms of gas, 10-15 gallons of tar, and ammonia equivalent to about 25 lb. of ammonium sulphate. At gas works, some of the coke is used to make water gas, heat the retorts, and generate steam and power, so that the quantity of coke available for sale is roughly 9 cwt. per ton of coal. At coke ovens, a large proportion of the coal gas is used to heat the ovens. The coke is used mainly for blast furnaces and other furnaces,

though some is sold for other industrial purposes and sometimes for domestic use. Much of the surplus gas is sold to gas works.

It is difficult to give an estimate for the efficiency of use of coke for the many and varied industrial purposes for which it is employed. Though it can be used with high efficiency in industrial boilers and for making producer gas, the efficiency with many furnaces is low. It is unlikely that the overall average is more than 50 per cent.

With coke for the open domestic fire with a grate suitable for burning this fuel, the efficiency under average conditions is roughly 25 per cent, and it could no doubt be increased to about 30 per cent, as with the open coal fire, if provision for heating by convection as well as radiation were included. In closed stoves and boilers (with hot-water radiators) of the usual domestic type, the efficiency of using coke is in the region of 50 per cent.

The efficiency of gas appliances in general is higher than with appliances using coal or coke. Modern gas fires have an efficiency of 40-50 per cent under average conditions.

In considering these figures for coke and gas, which are intended to represent overall average, not test, conditions, it should be remembered that in order properly to compare them with the figures for coal, they should be reduced to allow for the fact that heat is used and lost in making coke and gas from coal. If the efficiency of production is taken as 75 per cent, the efficiency in use should be multiplied by 0.75 to give the 'coal economy efficiency'.

Though much attention has been given to fuel economy by railway undertakings, the overall efficiency of use of coal for power for locomotives is necessarily low. Including shunting operations, the overall average is well below 10 per cent, and is probably not more than about 5 per cent.

Nature and Amount of Pollution

Of the various products of combustion or partial combustion, those which give rise to pollution of the atmosphere are mentioned in Table 2.

TABLE 2. POLLUTING SUBSTANCES FROM COAL AND PRODUCTS.

(a) Solid.	Particles of carbon causing black smoke and particles of mineral matter or ash carried forward with the gaseous products.
(b) Liquid carbonaceous material.	Fine particles of liquid tarry matter causing yellowish or brown smoke.
(c) Unburned and partially burned gases.	Gaseous hydrocarbons and carbon monoxide.
(d) Sulphur oxides.	Sulphur dioxide and some sulphur trioxide which with water forms sulphuric acid.

It is not easy to assess the amounts of those forms of pollution produced by the various fuels with their different methods of use, and only approximate estimates can be given. It is worthy of note, however, that the methods of measuring amounts of pollution are steadily being improved. For example, during recent years considerable attention has been given at the Fuel Research Station of the Department of Scientific and Industrial Research to the measurement of the quantity of smoke emitted from domestic fires and industrial boilers using coal; and a satisfactory method has been devised. A detailed description of the method is being prepared for publication. It is based on measurements of the amount of light absorbed by the smoke-laden gases when a beam of light under standard conditions is passed through a layer of the gases; many difficulties had to be over-

come before a technique of sufficient accuracy and reliability was devised. As a result of this work, the figures now available are much more reliable than those previously obtained. Though the quantity of smoke emitted from the domestic fire is high, this latest investigation has shown that it is not so great as has often been stated.

In Table 3, approximate estimates are given, on the basis of the best available information, of the total amount of pollution produced annually from the use of coal in Great Britain under the conditions during the few years preceding the War.

TABLE 3. NATURE AND QUANTITY OF POLLUTION FROM COAL IN GREAT BRITAIN.

Type and use of fuel	Quantity of coal (millions of tons per annum)	Pollution produced (millions of tons per annum)		
		Smoke	Ash	Sulphur dioxide
Coal:				
Domestic grates	42	1.1	0.1	1.0
Electricity power stations	14	small	0.1	0.4
Railways	13	0.4	0.1	0.4
Collieries and various industrial uses	68	0.8	0.2	2.4
Coke and Gas:				
Coke ovens and use of coke	20	small	small	0.5
Gas industry at gas works in using gas	19	small	small	0.1
in using coke		nil	nil	small
Total	176	2.3	0.5	5.0

From the figures in this table, the weight of tarry and carbonaceous matter in the smoke produced is 2-2½ million tons a year, or roughly 1½ per cent of the weight of the coal used. Approximately one half of this weight of smoke is derived from domestic grates, which use only about one quarter of the coal. The total pollution by oxides of sulphur is about 5 million tons a year, and the weight of the grit or ash discharged into the atmosphere is roughly 0.5 million tons. Not more than one fifth of the sulphur and grit arises from domestic appliances burning raw coal.

Reduction in Pollution

In the present state of knowledge and of development of fuel-burning appliances, it is not practicable entirely to prevent the pollution of the atmosphere through the use of coal and its products. It is practicable, however, to effect a considerable reduction in the amount of the pollution caused by smoke and grit, though it is much more difficult to reduce the amount of pollution from sulphurous gases. How can such an improvement be effected? There is no one method. Developments and changes in several directions are necessary.

In the first place, all practicable steps must be taken at the colliery to clean the coal before delivery to the consumer. A reduction in the adventitious mineral matter will reduce generally the solid matter to be removed when the coal or coke is burned, and the quantity of sulphurous gases discharged into the chimney. It is apparent also that as the best coal seams are gradually worked out the need for efficient cleaning will become greater.

The next important step is to ensure that the coal and its products, coke, gas and electricity, are used as efficiently as is economically practicable, and that the heat and power developed are not wasted. Efficient use of fuel can only be achieved as a result of skilled and intelligent operation, maintenance of fuel-using appliances in good condition, development of better

appliances, and the judicious application of insulating materials to reduce waste of heat. In Great Britain insufficient attention has been given to the training of fuel technologists and operators, and little attention has been given to the possibilities of insulating buildings with the object of conserving heat.

With large modern boiler installations equipped with mechanical stokers, little or no smoke need be produced; but installations of this kind with forced draught carry appreciable quantities of ash or grit into the chimney gases. Most of the grit can be removed from the chimney gases by the use of efficient grit-catchers such as have been installed at the largest electricity generating stations. There might well be extension of the application of this method to other boiler and furnace installations. At certain of the largest electricity power stations in thickly populated areas of Britain, coals containing not more than 1 per cent of sulphur are selected for firing the boiler furnaces. In addition, these power stations are equipped for the operation of processes which remove most of the oxides of sulphur from the chimney gases before discharge to the atmosphere. These processes of treatment to remove sulphurous gases, however, are not easily operated and are expensive; their cost on pre-war prices was 2-3s. per ton of coal burnt. There is required some efficient but cheaper method of reducing the quantity of oxides of sulphur discharged, suitable not only for the largest but also for smaller boiler installations. This difficult problem is being studied, but there is no immediate solution in sight.

It has not been possible in the past, with the large numbers of hand-fired boilers at numerous industrial works, to avoid the emission of smoke, particularly for a time after stoking. As a result of extensive work by the Fuel Research Station during the last few years, equipment has been developed to replace the doors of marine and Lancashire boilers, whereby the emission of smoke can be practically eliminated. The equipment is simple to construct and very simple to operate. It provides at the right time and in the right way the extra air required to burn the smoky volatile matter evolved from the fresh coal for the necessary period after stoking. This equipment is already in satisfactory use on many hundreds of marine boilers, and its value has been fully demonstrated; not only does it greatly reduce the amount of smoke, but also it assists in maintaining high efficiency in utilizing the heat value of the coal.

The domestic open fire produces more smoke per ton of coal burned than any other appliance in general use; it has already been mentioned that about one half of the smoke pollution arises from domestic appliances, though they consume less than one quarter of the total coal used, or less than one third of the coal burnt direct and not submitted to such processes as carbonization. Though the problem has been studied by many investigators, there is no immediate prospect of designing an open fire which will burn bituminous coal without producing any smoke. There are designs of open fire, however, which will bring about a reduction in the amount of smoke to about one half of that with the open fire of usual type, but they have not yet been tried out in general use by the average householder. The emission of smoke during the early stages of burning up after lighting seems to be unavoidable.

There is at present no method of reducing the amount of pollution by sulphurous gases from each ton of solid fuel burnt in domestic appliances,

whether the fuel is coal or coke; the proportion of sulphur in coke is roughly the same as in the coal from which it is made.

Pollution by grit from the burning of coal and coke in domestic appliances is not easily prevented, though fortunately it is not very great.

Substitution of gas for solid fuel would avoid pollution by smoke and grit and would reduce pollution by sulphurous gases to a negligible amount. The use of electricity in place of solid fuel avoids the production of smoke, but would not prevent pollution by grit and sulphurous gases unless the generating stations are equipped to remove the grit and sulphur from the chimney gases. In general, however, gas and electricity are too expensive for continuous heating in the average house, but they have advantages in many circumstances for short-period intermittent heating and for cooking.

So far as domestic appliances are concerned it would seem that encouragement should be given to the use of coke, gas, and electricity in place of coal, so far as is economically practicable, if atmospheric pollution is to be greatly reduced. But the changes suggested could only take place gradually, if the demands for the various fuels and forms of energy are not to overstep the supply; and there must be a suitable balance if the resources of the different types of coal are to be used to the best advantage in the broad national interest. It should be pointed out that all the possibilities have not been covered: for example, the possibilities of communal central heating and district heating have not been discussed. It is hoped, however, that this broad review will serve to indicate the general lines along which progress can be made.

COAL MINING IN GREAT BRITAIN

IT would be difficult to exaggerate the importance of the Report of the Technical Advisory Committee on Coal Mining, presumably to be known as the Reid Report*. For almost a century, coal mining in Great Britain and its special aspects have been the subject of inquiry for royal commissions and departmental committees, and in the past few months much has been written on the reorganization of the industry. However, the Reid Report is without parallel. Seven distinguished mining engineers have examined the present lamentable position, and have set out in detail their proposals for the creation of a prosperous and efficient industry. Mr. Reid and his colleagues have expressed their views with complete frankness, and have criticized impartially mine-owner, mining engineer and workman. If ever the term 'blue-print' could be applied to a document, then this report is a blue-print for the post-war mining industry in Britain.

The approach to the problem is historical, and Part I includes a revealing comparison of the coal industry of Britain with those of the principal Continental nations. If two nations are mining coal under approximately similar natural conditions, then the output of coal per man-shift worked can be regarded as a measure of the efficiency of mining. Similarly, records of output per man-shift over several years will provide evidence of improvement or de-

terioration in the mining situation of a particular nation. In any comparison of statistics of output per man-shift careful account must be taken of the natural conditions under which the coal is worked. In the United States, mining conditions are greatly superior to those prevailing in Britain, and in Poland mining is carried on under the best natural conditions in Europe. However, in Holland and on the Ruhr, conditions are certainly no better than those of the British coalfields. Although useful conclusions can be drawn from the statistics of American mining, for a fair comparison we must turn to our Continental neighbours, and particularly to Holland and the Ruhr.

Those who desire an account of the vicissitudes of the British coal trade must refer to the report itself. The most significant period is that between the years 1927 and 1939, and it is sufficient here to say that, in spite of the introduction of several thousand mechanical coalcutters during the years 1913-27, output per man-shift showed little improvement from the 20.32 cwt. of 1913 to the 20.62 cwt. of 1927. Some progress was made in the years 1927-36, when the output increased by some 14 per cent to 23.54 cwt., a maximum for the period between the Wars. Small as the increase appears, it was achieved only as a result of intensive mechanization—the tonnage of coal mechanically cut increased from 58.5 to 142.2 million tons between 1927 and 1939, while the tonnage carried on face conveyors increased from 28 millions in 1928 to 134 millions in 1939. Taking Great Britain as a whole, the situation in the coal mines left little room for complacency.

In 1914 Britain was able to dominate the sea-borne coal trade of the world, and substantially retained this position until 1925, when Poland and Germany first assumed the position of serious competitors. To compare British and Continental progress the Committee has adopted as the basic year that in which each country attained the 1913 level of output per man-shift, and the following table is extracted from the report.

Country	Basic year	Output per man-shift		Percentage increase
		in basic year	in 1936	
Poland	1927	23.44 cwt.	36.20	54
Holland	1925	16.48	35.94	118
The Ruhr	1925	18.62	33.66	81
Britain	1927	20.62	23.54	14

Comparison with the United States would be unjustified, but it should be noted that the output per man-shift in the American bituminous mines amounted to 93.8 cwt. in 1939.

Many reasons are advanced for this failure to attain, or even approach, Continental standards of output. The British industry has long lacked the financial resources to undertake major long-term improvements, and considering the low average profit per ton—7d. during the years 1929-38—this is not surprising. Conditions of mineral ownership have proved a disastrous handicap to the mines of Britain. Until 1942 the minerals were privately owned, and there remains a legacy of small and awkwardly shaped leaseholds, worked by an excessive number of mines, many of which are of low capacity. On the Continent the amalgamation of undertakings has resulted in the concentration of production in large well-equipped mines. In 1938 the Ruhr mines were of an average capacity of 778,000 tons per year;

* Ministry of Fuel and Power. Coal Mining: Report of the Technical Advisory Committee. (Cmd. 6610.) Pp. ix+150. (London: H.M. Stationery Office, 1945.) 1s. net.