

Gas works, coke works and other coal carbonisation plants

Industry Profiles, together with the Contaminated Land Research Report series, are financed under the Department of the Environment's contaminated land research programme.

The purpose of these publications is to provide regulators, developers and other interested parties with authoritative and researched advice on how best to identify, assess and tackle the problems associated with land contamination. The publications cannot address the specific circumstances of each site, since every site is unique. Anyone using the information in a publication must, therefore, make appropriate and specific assessments of any particular site or group of sites. Neither the Department or the contractor it employs can accept liabilities resulting from the use or interpretation of the contents of the publications.

The Department's Contaminated Land Research Report series deals with information needed to assess risks; procedures for categorising and assessing risks; and evaluation and selection of remedial measures.

General guidance on assessing contaminated land and developing remedial solutions which is complementary to the Department's publications is provided by the Construction Industry Research and Information Association (CIRIA).

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DOE Industry Profile

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Preface

DOE Industry Profiles provide developers, local authorities and anyone else interested in contaminated land, with information on the processes, materials and wastes associated with individual industries. They are not definitive studies but they introduce some of the technical considerations that need to be borne in mind at the start of an investigation for possible contamination.

Every site is unique. Investigation of a site should begin with documentary research to establish past uses. Information on the site's history helps to focus a more detailed investigation. This knowledge needs to be supplemented by information on the type of contamination that may be present and where on site it may be found. Profiles give information on the contamination which might be associated with specific industries, factors that affect the likely presence of contamination, the effect of mobility of contaminants and guidance on potential contaminants.

The date when industrial practices first commenced on a site and its location are important clues in establishing the types of operations that may have taken place, so each profile provides a summary of the history of the industry and its likely geographical spread within the United Kingdom.

Profiles should be read with the following reservations in mind:

- individual sites will not necessarily have all of the characteristics described in the profile of that industry;

- practices can vary between sites and change over time;

- as practices change, problems of possible contamination may also change;

- the profile may refer to practices which are no longer followed, and may omit current practices which avoid contamination.

The risks presented by contaminated sites depend on the nature of the contaminants, the targets to which they are a potential threat (such as humans or groundwater) and the routes or pathways by which they reach these targets. The current or proposed use of a site and its environmental setting are crucial in deciding whether treatment is necessary and if so, the methods to be used. Some sites may not need treatment.

The information in profiles may help in carrying out Control of Substances Hazardous to Health (COSHH) assessments for work on contaminated land - see Health and Safety Guidance Note HS(G) 66 *Protection of workers and the general public during the development of contaminated land*, Health and Safety Executive, 1991, and *A guide to safe working practices for contaminated sites*, Construction Industry Research and Information Association, 1995.

Note: the chemical names given to substances in this profile are often not the modern chemical nomenclature, but the names used historically for those substances.

Gas works, coke works and other coal carbonisation works

1. Background

The coal carbonisation industry developed through the 19th Century with three main branches: coke production, gas production and tar distillation. The process of coal carbonisation has remained broadly the same throughout the history of the industry. The process involves heating coal in the absence of air to produce coal gas, coke, tar and ammoniacal liquor.

Historically, coke was required in large quantities by the iron and steel industries; coke production has declined from a peak in the mid-1950s as the iron and steel industry has contracted. (Information on the iron and steel industries is contained in a separate profile in this series - see Section 4). Coke is used today in the metallurgical industries - in 1986 there were 16 sites where coke was manufactured for these industries; at present (1995) there are only 4 sites in the United Kingdom.

Coal gas started to be widely used as a means of illumination in the United Kingdom in the early 19th Century, initially in factories and subsequently for street lighting. The London and Westminster Gas, Light and Coke Company was founded in 1813 and, by the early 1820s, gas works producing gas for lighting were established in many cities. It was not until the mid-19th Century that gas was used for domestic lighting. The development of electric lighting in the 1880s provided the incentive for the development of additional uses of coal gas such as heating and cooking. The coal carbonisation process was the major source of town gas until after the First World War when an increasing proportion of gas was produced as carburetted water gas. In the late 1950s and early 1960s a number of gas works took advantage of cheap refinery products and converted to oil reforming plants, manufacturing synthetic town gas (oil-gas) from petroleum. Following the introduction of natural gas, town gas production declined. The majority of town gas works closed in the 1960s and, with a few exceptions, the plants producing synthetic town gas from petroleum were closed in the 1970s.

Census of Production data show that in 1930 there were just under 1800 gas and coke works and coal carbonisation plants. By 1935 this figure had fallen to 1514, of which 1395 were gas works; 40% of the establishments employed less than 10 people, and 55% employed 11-300 people. When the Gas Council was formed following nationalisation in 1949, there were about 1050 gas works and, by 1958, only 536. At present there are no gaswork sites in operation.

In 1935, the distribution of gas works and coal carbonisation plants employing more than 10 people was related to population density, being fairly evenly distributed throughout the United Kingdom, with slightly more in the industrial areas. For example, in Lancashire and Cheshire there were 102 plants, in the West Riding of Yorkshire 119, and in both the South East of England and Greater London, 84. The plants were generally situated within urban areas where the gas was used, but were also located at steel works and coking plants. gas works were often sited at that part of their distribution network which was at the lowest elevation, regardless of the ground conditions. Sites ranged from smaller works, producing

town gas only, to large sites where coke production may have been the main process or where tar distillation or other associated processes were undertaken in addition to gas production. Site sizes may range from as little as 0.3 hectares to over 100 hectares.

Coal tar, one of the by-products of coal carbonisation, was used in the past as a source of organic chemicals. At the peak of this application, in 1926, there were 400 tar distillation works in the United Kingdom. Production of organic chemicals from coal tar distillates declined rapidly in the 1960s as the manufacture of coal-based town gas was replaced by oil reforming processes; natural gas and the oil refining industry are now the sources of organic chemicals. (Information on organic chemicals production is contained in a separate profile in this series - see Section 4). Only 4 coal carbonisation plants still operate for the production of domestic smokeless fuels. The metallurgical coke works also produce tar by-products. As a result, a small number of coal tar and by-products works continue in operation.

Natural gas displaced manufactured gas in towns, using the distribution networks already in place. For long distance transmission, natural gas must be transported at very high pressures (eg 66 atmospheres). Many coal-fired power stations are being converted to burn natural gas, leading to cleaner emissions (ie less sulphur dioxide).

The natural gas found in crude oil reservoirs is known as associated gas. Most natural gas extracted and used today in the United Kingdom (90%) is dry or non-associated, ie it occurs in reservoirs separate from those containing crude oil. If remaining gas resources are included, the proportion of dry gas to associated gas is 80%. The dry gas comes from the Southern Basin (the North Sea south of Teesside) and the associated gas from the north and central parts of the North Sea and from the Irish Sea.

2. Production processes

Coal carbonisation involves heating coal in the absence of air to produce coal gas, coke, tar and ammoniacal liquor. The yield and quality of gas, coke and tar can be varied by the process conditions (eg temperature), design of the ovens (eg horizontal or vertical) and composition of the coal. High temperature carbonisation gives a higher yield of gas and leaves less volatile material in the residual coke. Low temperature carbonisation is used for the manufacture of smokeless fuels and results in relatively lower gas yields and a coal tar which contains a high proportion of volatile components.

2.1 Coal gas production

Gas production by coal carbonisation involved heating the coal in ovens, or retorts, with a limited supply of oxygen at high temperatures. The gas stream leaving the ovens contained impure coal gas, ammoniacal liquor and tar. The liquid fractions were separated and the gas was purified to remove remaining ammonia, tar, hydrocarbon oils and sulphur compounds. The final coal gas (town gas) contained more than 50% hydrogen, carbon monoxide and some hydrocarbons.

2.1.1 Gas cleaning

The majority of the tar and water vapour contained in the gas at the outlet of the retort house was removed (as liquor) in condensers. Most of the associated ammonia and hydrogen sulphide was dissolved in this liquor. The residual tar was removed using Livesey washers or, in later gas works, electrostatic precipitators. The remaining ammonia and some hydrogen sulphide and hydrogen cyanide were removed by scrubbing the gas with water or weak ammoniacal liquor.

For use as town gas further purification was required to reduce the hydrogen sulphide content of the gas. Gas leaving the ammonia scrubbers could contain up to 2% (20 000 ppm) hydrogen sulphide but the statutory requirements for the quality of distributed gas set a limit of 0.7 ppm. The early gas works used slaked lime (calcium hydroxide) to remove hydrogen sulphide. This process produced foul lime (a mixture of slaked lime, calcium hydrosulphide and calcium thiocarbonate) which could not be recycled or used in other processes. Weathering of foul lime wastes led to odour problems from the emission of hydrogen sulphide.

Between 1850 and 1900, the use of slaked lime to remove hydrogen sulphide gradually gave way to the use of iron oxide in the form of 'bog ore' (hydrated ferric oxide mixed with peat or, more recently, wood shavings). The product was ferric sulphide. Regenerated oxide was returned to use until its elemental sulphur content reached 40-50%; at this level it was economical to use the spent oxide as a feedstock for sulphuric acid manufacture. The iron oxide also removed hydrogen cyanide from the gas, resulting in the formation of complex cyanides.

In the 1930s, a small number of coal gas works replaced the iron oxide process with liquid purification systems. A number of different absorbents were used, including:

- hot sodium carbonate solution with regeneration of absorbent by air;
- sodium thioarsenate solution (the Thylox process) with regeneration by air;
- triethanolamine with regeneration by steam;
- sodium phenoxide with regeneration by steam.

In larger works, the gas was subjected to an additional purification step in which benzol (crude benzene, a mixture of aromatic hydrocarbons) was removed by scrubbing with gas oil (a fraction obtained by the distillation of petroleum). The benzol was then distilled from solution and submitted to by-product processing.

2.2 Producer gas production

Initially, coal, coke, tar or coal gas itself were burnt to heat the carbonisation retorts but these fuels were replaced by 'producer gas' for town gas production. Producer gas was manufactured in a strongly exothermic reaction (ie involving the evolution of heat) by blowing air over hot coke and it was essentially a mixture of carbon monoxide and nitrogen. Producer gas manufacture resulted in a clinker waste, from fusion of the ash.

2.3 Carburetted water gas (CWG) production

Water gas consisted of a mixture of carbon monoxide, carbon dioxide and hydrogen and was manufactured by passing steam over red hot coke in a strongly endothermic reaction (ie involving the absorption of heat). As the reaction was endothermic, water gas plants were typically cyclic operations, alternately blowing

air over incandescent coke to make producer gas, burning it to raise heat, and then blowing steam to make water gas.

The water gas was enriched by the addition of a range of high calorific value hydrocarbons arising from the thermal degradation of oil. This enriched gas was known as carburetted water gas (CWG) and was mixed with coal gas prior to distribution. CWG was used to raise the calorific value of the distributed gas at times of peak demand.

Tar was a by-product of CWG production. This tar differed from coal tar in that it was formed by pyrolysis of naphtha or gas oil. It contained lower concentrations of toxic substances, such as pyridine and thiophenes, and so was regarded as a less objectionable substance than coal tar.

2.4 Oil-reforming plant

In the late 1950s and early 1960s a number of gas works converted part of their generating capacity to the production of oil-gas (ie gas from oil). This was produced by continuously reacting various hydrocarbon feedstocks, including liquefied petroleum gas, light distillate spirit and naphtha, with steam in the presence of a catalyst. Oil-gas consists chiefly of methane, ethylene, acetylene and benzene, with some heavier hydrocarbons. Typically, oil-gas was odourless and was deliberately provided with an odour similar to the coal-based town gas which it replaced. A range of odourants was employed, based on tertiary butyl mercaptan, tetrahydrothiophen, diethyl sulphide and other mercaptans.

2.4.1 Low pressure reforming

In the early reforming plants, the gas was produced by cracking oil in the presence of steam at atmospheric pressure and at temperatures between 900 and 1000°C. A catalyst, either magnesite/lime or nickel, was used to promote the reaction between steam and hydrocarbon. The use of a catalyst resulted in increased gas yield and reduced tar and/or carbon production.

The production process involved spraying oil into pre-heated steam in a vaporising chamber. The mixture of steam and hydrocarbon vapour was then passed through the catalyst chamber where the desired reaction occurred. The gas, which was for practical purposes stable by the time it reached the bottom of the catalyst chamber, was then passed through an air preheater for heat transfer, through a wash box and into a relief holder.

The tar produced was similar to that from the CWG process. It was separated in the washbox with the aid of surface active agents such as 'Amine 220' and 'Fatchemco TEB'. The carbon produced when cracking light feedstocks floated on the surface of the settling tanks and was removed by means of skimmers.

2.4.2 High pressure reforming

In more recent reforming plants, gas generation involved continuous vapour phase reactions conducted at high pressure in the presence of a catalyst, to produce a low calorific value gas which was enriched before distribution.

The catalysts used were generally ceramic, promoted with nickel oxide, although on rare occasions uranium oxide promoters were used. Other catalysts were:

iron oxide/chromium oxide, to promote the conversion of carbon monoxide to carbon dioxide;

mixed cobalt oxide/molybdenum oxide or nickel oxide/molybdenum oxide systems used to hydrogenate sulphur compounds in the hydrocarbon feedstocks, prior to desulphurisation using zinc oxide.

Carbon dioxide was removed from the gas stream by absorption with potassium carbonate solution, activated with sodium metavanadate (or in a minority of plants, with arsenic salts). Other process chemicals included:

triethanolamine, used as a drying agent for the gas;
acids and caustic soda for water treatment;
phosphates, sulphides and hydrazine for boilers;
corrosion inhibitors and biocides for cooling towers;
various anticorrosion additives to protect the drying vessels eg 2-mercaptobenzothiazole.

The high pressure reforming process was essentially clean and did not produce the tar and effluents which are commonly associated with other town gas production processes. The wastes associated with high pressure reforming were mainly wastewater from the carbon dioxide scrubbing plant, from the boiler blow down and from the water treatment works.

2.5 Natural gas production

In its raw state, natural gas consists principally of methane and ethane, with fractional amounts of heavier hydrocarbons such as propane, butane, pentane, hexane, heptane and octane. Dry gas contains much less of these heavier hydrocarbons than does associated gas. All the ethane and heavier components of natural gas are easily separated from the gas stream and liquefied under moderate pressure.

Most of the heavier components are recovered for their added value as separate products. Recovery and separation relies principally on the differences in boiling points and vapour pressures of the various components. The heavier the hydrocarbon component, the higher its boiling point; therefore if the raw natural gas is cooled to a certain temperature, all components with boiling points above this temperature will liquefy out. Refrigeration is combined with oil absorption for optimum recovery. A heavy absorption oil, which has good solubility for propane and the heavier hydrocarbons, is used to remove these from the natural gas; the oil is recirculated.

Most of the ethane and propane recovered are used as cracking feedstocks for ethylene and propylene manufacture. (This process is described in a separate profile covering oil refineries, see Section 4). Pentane and butane are used for vehicle fuel, and propane is also used as a bottled fuel for areas outside the natural gas network.

In addition to hydrocarbon components, natural gas from some reservoirs may contain varying amounts of hydrogen sulphide, carbon dioxide, water, nitrogen and helium. To produce a saleable gas, water, carbon dioxide and hydrogen sulphide are removed to prevent freezing, clogging, corrosion or other operating problems in

transmission and utilisation. In the presence of water, natural gas can form hydrates (cage-like crystals of water trapping the hydrocarbon molecules inside) which look like snow and can plug up pipelines at temperatures well above freezing.

Hydrate formation can be prevented either by dehydrating the gas or by adding inhibitors. Dehydration can be accomplished through the use of a liquid desiccant (triethylene glycol) or solid desiccants (alumina, silica gel or synthetic resins). Inhibitors are almost exclusively methyl alcohol, ethylene glycol or diethylene glycol. Hydrogen sulphide and carbon dioxide are removed using an alkanolamine with the hydrogen sulphide being converted to sulphur.

2.6 Coke production

Coal carbonisation was the main method for the production of coke. Originally coke was produced in beehive ovens where the volatile matter and gas emitted were burned above the coal to provide heat for the coke making process. Beehive ovens were used exclusively until around 1850 when attempts were made to improve the design of 'by-product ovens'. The development of various heat economy devices produced surplus gas which was made available to the town gas supply.

Although coke ovens were installed at a number of gas works, most were located at iron and steel works where the coke was used. From 1950, low temperature coal carbonisation was used to provide smokeless fuels. The production of these has decreased as oil and gas have taken their place for heating purposes.

2.7 Ancillary processes

The by-products of the coal carbonisation process were regarded as an important source of raw materials for both the inorganic and organic chemical industries.

2.7.1 Tar distillation

A range of chemicals derived from tar distillation products provided the main feedstock for the organic chemical industry until the massive expansion of the petrochemical industry after the Second World War.

Coal tar removed from coal gas at various cleaning stages was collected and stored in wells or tanks, which were frequently located underground. At larger sites sufficient coal tar was produced for use as a feedstock for tar distilleries which were often located near the larger gas and coke works. At smaller sites the tar was treated as waste.

Coal tar was subjected to fractional distillation and chemical processing, initially producing a range of mixed hydrocarbon and other products, for example motor benzol, solvent naphtha, creosote, various grades of pitch and road tar. As the needs of industry developed, increasing sophistication was applied to the coal tar by-product processes. A combination of further fractional distillation and chemical processing made available a wide range of pure organic chemicals, eg benzene, toluene, xylene, phenols, cresols, xyenols, pyridine, naphthalene, anthracene etc, for use in the chemicals industry.

2.7.2 Ammonia recovery

Until the early 20th Century, ammoniacal liquor from coal carbonisation was almost the sole source of ammonia for industry.

The most common method of recovering ammonia from ammoniacal liquors was through the use of a continuous still. Ammoniacal liquor was passed through an upward moving stream of steam, free ammonia was released with the steam and carried to the top of the still. Fixed ammonia was released by distilling with strong alkali. On leaving the still the steam-ammonia mixture, which also contained impurities such as carbon dioxide, hydrogen sulphide and hydrogen cyanide, entered a saturator containing sulphuric acid in which the ammonia was absorbed and precipitated as ammonium sulphate.

The excess steam, carbon dioxide and hydrogen sulphide passed from the saturator through heat exchangers and condensers where compounds such as phenols and hydrogen sulphide were condensed out. The condensate, known as 'devil liquor', was returned to the plant for redistillation. The uncondensed gases were discharged to the atmosphere after the hydrogen sulphide and cyanide had been removed.

2.7.3 Sulphuric acid manufacture

Sulphuric acid was manufactured by the lead chamber process, using sulphur dioxide from roasting spent iron oxide (see Section 2.1.1). Fertiliser grade ammonium sulphate was a major product of coal carbonisation by-product works, derived from this sulphuric acid and from ammonia in ammoniacal liquor.

2.7.4 Steam production

Steam was required for distillation and this was often obtained using boilers fed with waste heat. Coke, oil or tar burning boilers were also used. Treatments to the feed water may have included softening and conditioning with phosphates, sodium sulphate and tannins.

2.8 Wastes

2.8.1 Ammoniacal liquor

Ammoniacal liquors are polluting liquids whose main components are 'free' and 'fixed' ammonia. Phenol is also present but in small quantities. Free ammonia derives from ammonium salts such as sulphide, cyanide, carbonate and bicarbonate that decompose on heating to give ammonia. Fixed ammonia is present in ammonium salts such as chloride, thiocyanate, ferrocyanide, thiosulphate and sulphate, from which ammonia is only liberated by addition of caustic alkali.

The ammoniacal liquor was stored in underground tanks. Soils containing ammoniacal liquor can be identified by their characteristic odour.

2.8.2 Coal tar

Coal tars are a complex mixture of various organic components (see Annex for the principal components).

Most of the coal tar produced was either sold to larger gas works or chemical companies, or it was used on site in tar distillation or as a fuel. At some small sites it was often disposed of on site in ponds or lagoons, but in most cases it was kept in underground tanks. The tanks were normally brick-walled and surrounded by puddle clay, so that leakage from them was small, but some contamination of the surrounding soil lining may have occurred as a result of leaks from tanks and pipes.

Coal tar is a black/brown viscous liquid with distinctive 'organic' odour. The pungent smell of coal tar makes it easily identifiable even in small quantities in soil. The odour level depends on the soil type and is more marked in clay and sand than peat or loam.

2.8.3 Spent oxide

Spent oxide resulted from gas purification using iron oxide and was regarded as a by-product useful for the dye industry (as Prussian Blue). If the spent oxide was of sufficiently high sulphur content it would have been sold to a sulphuric acid manufacturer. However, on some small sites where sulphur recovery was not practicable, it was disposed of on site as waste. Spent oxide is a very acidic material with a high free sulphur content of 35-60%, sulphate content of 2-3% and a total cyanide content of 3-6% (the cyanide is mainly in the form of complex cyanides and thiocyanates).

Owing to the presence of ferric ferrocyanide (Prussian Blue), spent oxide is easily distinguishable by its blue colour; a concentration of 1% in the soil is detectable by colour. Spent oxide can also be identified by its characteristic sulphurous odour.

Spent oxide is likely to be found on or near the surface (depending on the extent of rebuilding and redevelopment of the site) where it was dumped and may appear as dust. On some sites spent oxide was used as a fill material and may therefore also be found at depth. Residues may still be present in the process buildings and on railway sidings if the spent oxide was moved by train.

2.8.4 Foul lime

Foul lime (see Section 2.1.1 for components) resulted from gas purification using slaked lime. The material presented a major disposal problem and accumulated on site in heaps. Weathering of the foul lime may give rise to hydrogen sulphide, but the major environmental problem associated with it is its rock-hard consistency.

2.8.5 Metals

Heavy metals are present as trace elements in 'bog ore' (hydrated ferric oxide mixed with peat), coal, coke, spent oxide and foul lime. Metal oxides (see Annex) have been employed in the carbonisation process as catalysts and corrosion inhibitors. Lead was used in paintwork, as caulking for gas holders and in pipework.

Heavy metals may be widely distributed on gas works sites. However, it is likely that higher heavy metal concentrations will be found around old process areas, former coal storage sites and areas used for the disposal of spent oxide and/or other process residues.

2.8.6 Coal dust

Contamination by coal dust results from the stockpiling of coal and is likely to be concentrated in former coal storage/breaking areas. Carbon residues may also be in the form of an impacted coal carpet in areas where coal or coke has been in use or stored for many years.

Soil containing coal dust can be recognised by its blackened colour or the presence of larger coal particles.

3. Contamination

The contaminants on a site will largely depend on the history of the site and on the range of materials produced there. Potential contaminants are listed in the Annex and the probable locations on site of the main groups of contaminants are shown in Table 1. It is most unlikely that any one site will contain all of the contaminants listed. It is recommended that an appropriate site investigation be carried out to determine the exact nature of the contamination associated with individual sites.

3.1 Factors affecting contamination

Ground contamination is likely to be associated with the by-products and waste products of gas and coke manufacture and ancillary processes, eg ammoniacal liquor, coal tar, spent oxide and foul lime. Landfills and lagoons associated with coal carbonisation plants may have adversely affected watercourses, as a result of direct surface water run-off and migration of contamination in groundwater.

3.1.1 Landfills and above ground storage

Solid wastes and materials stored or disposed of above ground included:

- coal;
- clinker (also used as hard core);
- flue dust;
- boiler ash;
- foul lime (also used as hard core);
- spent oxide (may also be found at depth).

The presence of heavy metals may be expected in these areas.

3.1.2 Process buildings and railway sidings

Spent oxide and heavy metals may be found around old process areas. Any materials and wastes, eg coal and spent oxide, that were moved around the site by train, may be present near railway sidings.

3.1.3 Ponds and lagoons

Wastes stored or disposed of above ground in ponds and lagoons include water treatment sludges, consisting of mixtures of lime, calcium carbonate and similar compounds, acid tars and possibly coal tar.

3.1.4 Underground tanks and pipes

The remainder of tarry and liquid wastes, including coal tars, acid tars, sludges from tar-liquor wells, ammoniacal liquors and devil liquor (from ammonia recovery), would have been stored below ground in tanks. These tanks and underground pipes may have contaminated the ground through leakage. Additional contamination of the soil can result from damage to the buried pipes and tanks during site investigation work and redevelopment of the site.

3.1.5 Direct release to ground or sewer

Liquid wastes that may have been allowed to drain away on site or to the sewer, were ammoniacal liquor, gas tank sealing water and overflow water.

3.1.6 Wastewater treatment

Many major coke manufacturing sites, particularly in South Yorkshire and North Derbyshire, have at some time used colliery spoil tips for the secondary treatment of wastewater (known as spoil heap irrigation). There is a risk that land and groundwater could become contaminated from this wastewater.

3.2 Migration and persistence of contaminants

Some lower distillates of coal tar, for example phenol, are water soluble and may percolate in solution through the soil to groundwater or contaminate surface waters through run-off in rain water. Both ammonia and phenol are very soluble and therefore present a potential risk to ground and surface water. Phenols may migrate through plastic pipes.

Other lower distillates of coal tar, for example benzene and toluene, are mobile and are slightly soluble in water. The higher distillates of coal tar, eg polycyclic aromatic hydrocarbons (PAHs), are less mobile but may flow at a rate dependent on soil type, and migrate as floating tar on the groundwater. It requires only a small concentration of the soluble components of coal tar to contaminate water supplies.

Free cyanide and sulphate are water soluble and therefore percolation of rainwater through residues on or below ground could contaminate surface and groundwater. Thiocyanate, ferri- and ferrocyanide are also soluble to a limited extent and can thus contribute to water contamination. Spent oxide is acidic and complex cyanides are stable under acidic conditions.

Sulphates forming acids in the soil can attack concrete and cast iron. Sulphates may also cause the biochemical corrosion of cast iron through the action of sulphate-reducing bacteria in an oxygen deficient (eg wet) environment.

The movement of metals through the soil is significantly retarded by the presence of clay minerals and organic matter. The solubility of some metals may increase under acidic conditions (eg copper, zinc and lead). In other cases the relationship is more complex. For example, trivalent chromium is more soluble under acidic conditions, whereas the solubility of hexavalent chromium is increased under both acidic and alkaline conditions and arsenic may become more soluble at higher pH levels.

The mobility of coal residues is low, unless they are in the form of dusts, in which case wind removal and dispersal may spread them over a wide area.

Asbestos is not water soluble or mobile in soil, but can be transported by wind.

4. Sources of further information

4.1 Organisations

For information concerning specific gas works sites in the United Kingdom, the following organisation should be consulted:

Property Development Unit
British Gas plc
2 Bessborough Gardens
London
SW1V 3JE

Further specialist advice may be available from:

The Institution of Gas Engineers
17 Grosvenor Crescent
London
SW1X 7ES

4.2 Sources of further information concerning the activities described in this profile

Inter-departmental Committee on the Redevelopment of Contaminated Land. *Notes on the redevelopment of gas works sites.* ICRCL 18/79, 5th Edition, 1986.

Key A. *gas works effluents and ammonia.* Institution of Gas Engineers, Second edition, 1956.

Society of Chemical Industry. *Reclamation of contaminated land.* Proceedings of a Society of Chemical Industry Conference, Eastbourne, 22–25 October 1979. 1980.

Institution of Gas Engineers. *Entry into and work Associated with confined spaces.* IGE Safety Recommendations SR5. 1992.

Wilson D L and Stevens C. *Problems arising from the redevelopment of gas works and similar sites.* Second edition. Atomic Energy Research Establishment. London, HMSO, 1987.

Case study including information relevant to this Industry Profile:

Paul V. *Bibliography of case studies on contaminated land: investigation, remediation and redevelopment.* Garston, Building Research Establishment, 1995.

Estimates of the size and geographical distribution of the coal carbonisation industry have been obtained from the UK Census of Production and from yearbooks and directories related to the industry. Further information can be obtained from the following Central Government statistics, held principally by the Guildhall Library, Aldermanbury, London and the City Business Library, 1 Brewers Hall Garden, London:

Census of Production Reports. Board of Trade, HMSO (from 1924 to 1969).

Business Monitor Series: Annual Census of Production Reports. Central Statistical Office, HMSO (from 1970 to date).

Data on natural gas production can be found in:

The Energy Report: Oil and Gas Resources of the United Kingdom.
Department of Trade and Industry, HMSO, April 1994.

Information on researching the history of sites may be found in:

Department of the Environment. *Documentary research on industrial sites.*
DOE, 1994.

4.3 Related DOE Industry Profiles

Chemical works: organic chemicals manufacturing works
Metal manufacturing, refining and finishing works: iron and steelworks
Oil refineries and bulk storage of crude oil and petroleum products

4.4 Health, safety and environmental risks

The Notes issued by the Chief Inspector of Her Majesty's Inspectorate of Pollution (HMIP) provide guidance for the processes prescribed for integrated pollution control in Regulations made under the Environmental Protection Act 1990. Of particular relevance are:

Her Majesty's Inspectorate of Pollution. *Carbonisation and associated processes - coke manufacture.* Chief Inspector's Guidance to Inspectors, Process Guidance Note IPR 1/9. London, HMSO, 1992.

Her Majesty's Inspectorate of Pollution. *Carbonisation and associated processes - smokeless fuel, activated carbon and carbon black manufacture.* Chief Inspector's Guidance to Inspectors, Process Guidance Note IPR 1/10. London, HMSO, 1992.

Her Majesty's Inspectorate of Pollution. *Gasification processes - gasification of solid and liquid feedstocks.* Chief Inspector's Guidance to Inspectors, Process Guidance Note IPR 1/11. London, HMSO, 1992.

Her Majesty's Inspectorate of Pollution. *Gasification processes - refining of natural gas.* Chief Inspector's Guidance to Inspectors, Process Guidance Note IPR 1/12. London, HMSO, 1992.

Her Majesty's Inspectorate of Pollution. *Processes for the manufacture, use or release of oxides of sulphur, and the manufacture, recovery, condensation or distillation of sulphuric acid or oleum.* Chief Inspector's Guidance to Inspectors, Process Guidance Note IPR 4/10. London, HMSO, 1992.

Her Majesty's Inspectorate of Pollution. *Processes involving the use, release or recovery of ammonia.* Chief Inspector's Guidance to Inspectors, Process Guidance Note IPR 4/19. London, HMSO, 1993.

Her Majesty's Inspectorate of Pollution. *Tar and bitumen processes.* Chief Inspector's Guidance to Inspectors, Process guidance Note IPR 6/2. London, HMSO, 1995.

The Control of Substances Hazardous to Health (COSHH) Regulations 1994 and

the Management of Health and Safety at Work Regulations 1992 are available from HMSO. Information on relevant health and safety legislation and approved codes of practice published by HSE publications are available from Health and Safety Executive Books, PO Box 1999, Sudbury, Suffolk, CO10 6FS (telephone 01787 881165), as well as HMSO and other retailers.

Information on the health, safety and environmental hazards associated with individual contaminants mentioned in this profile may be obtained from the following sources:

Sax N and Lewis R. *Hazardous chemicals desk reference*. New York, Van Nostrand Reinhold Company, 1987.

Verschueren K. *Handbook of environmental data on organic chemicals*. 2nd Edition. New York, Van Nostrand Reinhold Company, 1983.

Howard P H. *Handbook of environmental fate and exposure data for organic chemicals*. Vols I and II. USA, Lewis Publishers, 1990.

4.5 Waste disposal and remediation options

Useful information may be obtained from the Department of the Environment series of Waste Management Papers, which contain details of the nature of industrial waste arisings, their treatment and disposal. A current list of titles in this series is available from HMSO Publications Centre, PO Box 276, London, SW8 5DT.

Publications containing information on the treatment options available for the remediation of contaminated land sites, prepared with the support of the Department of the Environment's Research Programme, can be obtained from National Environmental Technology Centre Library, F6, Culham, Abingdon, Oxfordshire, OX14 3DB.

A full list of current titles of Government publications on all aspects of contaminated land can be obtained from CLL Division, Room A323, Department of the Environment, Romney House, 43 Marsham Street, London, SW1P 3PY.

Advice on the assessment and remediation of contaminated land is contained in guidance published by the Construction Industry Research and Information Association (CIRIA), 6 Storey's Gate, Westminster, London, SW1P 3AU.

Annex Potential contaminants

The following contaminants, or their decomposition or reaction products, may be associated with a gas works or coal carbonisation site.

The chemical compounds and other materials listed below generally reflect those associated with the industry and which have the potential to contaminate the ground. The list is not exhaustive; neither does it imply that all these chemicals might be present nor that they have caused contamination.

Organic

Constituents of coal tar	aromatic hydrocarbons eg benzene, toluene, and xylenes polycyclic aromatic hydrocarbons (PAHs) eg naphthalene and anthracene hydroxy substituted phenyls eg phenols, cresol, xlenols and related compounds, sodium phenoxide heterocyclic nitrogen compounds eg pyridine organo-sulphur compounds eg thiophene nitrogen compounds eg hydrazine (boiler maintenance), triethanolamine 2-mercaptobenzothiazole
Natural gas processing	methyl alcohol ethylene glycol diethylene glycol triethylene glycol synthetic resins alkanolamine heavy absorption oil
Fuels	petroleum naphtha (low boiling point fractions of petroleum)

Inorganic

Acids	sulphuric hydrochloric
Alkalis	sodium hydroxide sodium carbonate

Other inorganic compounds	<ul style="list-style-type: none"> sulphates sulphides carbonates phosphates cyanides - mostly complex cyanides such as as ferricyanides and ferrocyanides ammonium sulphate and ammonium cyanide (from ammoniacal liquor) thiocyanates oxides elemental sulphur arsenatic salts calcium hydrosulphide and calcium thiocarbonate (foul lime)
Metals and metal compounds	<ul style="list-style-type: none"> cadmium chromium* cobalt* copper iron* lead nickel* manganese magnesium mercury molybdenum* uranium (only likely to be found on sites where uranium oxide was used as a catalyst in oil gas production) vanadium (only associated with reformer plants) as sodium metavanadate zinc*
Asbestos	

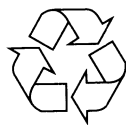
*oxides of cobalt, chromium, iron, molybdenum, nickel and zinc used as catalysts

Table 1 Main groups of contaminants and their probable locations

Gas works, coke works and other coal carbonisation plants

Contaminant	Location			
	Coal storage/breaking areas	Process areas	Tar pits, effluent tanks, lagoons pipework and pumps	Solid waste storage/disposal areas (inc made ground)
Ammonical liquors				
Coal tar				
Spent oxide Foul lime				
Metals				
Coal dust				

Shaded boxes indicate areas where contamination is most likely to occur



Recycled paper

DOE Industry Profiles

Airports

Animal and animal products processing works

Asbestos manufacturing works

Ceramics, cement and asphalt manufacturing works

Chemical works: coatings (paints and printing inks) manufacturing works

Chemical works: cosmetics and toiletries manufacturing works

Chemical works: disinfectants manufacturing works

Chemical works: explosives, propellants and pyrotechnics manufacturing works

Chemical works: fertiliser manufacturing works

Chemical works: fine chemicals manufacturing works

Chemical works: inorganic chemicals manufacturing works

Chemical works: linoleum, vinyl and bitumen-based floor covering manufacturing works

Chemical works: mastics, sealants, adhesives and roofing felt manufacturing works

Chemical works: organic chemicals manufacturing works

Chemical works: pesticides manufacturing works

Chemical works: pharmaceuticals manufacturing works

Chemical works: rubber processing works (including works manufacturing tyres or other rubber products)

Chemical works: soap and detergent manufacturing works

Dockyards and dockland

Engineering works: aircraft manufacturing works

Engineering works: electrical and electronic equipment manufacturing works (including works manufacturing equipment containing PCBs)

Engineering works: mechanical engineering and ordnance works

Engineering works: railway engineering works

Engineering works: shipbuilding, repair and shipbreaking (including naval shipyards)

Engineering works: vehicle manufacturing works

Gas works, coke works and other coal carbonisation plants

Metal manufacturing, refining and finishing works: electroplating and other metal finishing works

Metal manufacturing, refining and finishing works: iron and steelworks

Metal manufacturing, refining and finishing works: lead works

Metal manufacturing, refining and finishing works: non-ferrous metal works (excluding lead works)

Metal manufacturing, refining and finishing works: precious metal recovery works

Oil refineries and bulk storage of crude oil and petroleum products

Power stations (excluding nuclear power stations)

Pulp and paper manufacturing works

Railway land

Road vehicle fuelling, service and repair: garages and filling stations

Road vehicle fuelling, service and repair: transport and haulage centres

Sewage works and sewage farms

Textile works and dye works

Timber products manufacturing works

Timber treatment works

Waste recycling, treatment and disposal sites: drum and tank cleaning and recycling plants

Waste recycling, treatment and disposal sites: hazardous waste treatment plants

Waste recycling, treatment and disposal sites: landfills and other waste treatment or waste disposal sites

Waste recycling, treatment and disposal sites: metal recycling sites

Waste recycling, treatment and disposal sites: solvent recovery works

Profile of miscellaneous industries incorporating:

Charcoal works

Dry-cleaners

Fibreglass and fibreglass resins manufacturing works

Glass manufacturing works

Photographic processing industry

Printing and bookbinding works

Copies may be purchased from:

Publications Sales Unit

Block 3, Spur 7,

Government Buildings,

Lime Grove,

Ruislip, HA4 8SF

Price £10

Cheques payable to DOE.