Department of the Environment
Industry Profile

Chemical works

inorganic chemicals manufacturing works

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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.

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DOE Industry Profile

Chemical works: inorganic chemicals manufacturing works

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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.

Chemical works: inorganic chemicals manufacturing works

1. Background

The bulk inorganic chemicals industry is primarily concerned with the large scale conversion of relatively simple raw materials into feedstocks for further processing. The main compounds produced by the industry are chlorine, sodium hydroxide, sodium carbonate, sulphuric acid, nitric acid, ammonia, phosphoric acid, ammonium nitrate, urea and calcium oxide (lime).

The works dealt with in this profile are:

chlor-alkali works
sulphuric acid works
nitric acid and ammonia works
phosphoric acid works.

Each of these four types of works is discussed in a separate section of this profile.

Ammonium nitrate and urea are mostly used as fertilisers (see the Industry Profile dealing with the fertiliser industry, Section 9). The major use of lime today is in the manufacture of cement and plaster and its production is discussed in the Industry Profile on ceramics, cement and asphalt manufacturing works (see Section 9).

In 1948, a total of 510 establishments were recorded by the Census of Production as being involved in the manufacture of 'Chemicals (General)' which included miscellaneous chemicals, synthetic resins and plastic materials. This figure therefore indicates an upper limit to the size of the inorganic chemicals industry at that time.

Specific information on the numbers and location of works manufacturing inorganic chemicals (as separate from other types of chemicals) became available in 1963, when the Census of Production first classified inorganic chemicals separately. The data collected in 1963 indicate that at the time of the census a total of 262 inorganic chemicals manufacturing works were in operation.

Data collated for 1968 suggest that there was a wide range in the size of individual works (based on employee size), although only about 2% of the 306 works employed more that 750 workers. By 1993 the number of operational works had fallen to 173.

It should be noted that sites where inorganic chemicals manufacture has taken place may have a complex history of usage, including manufacture of organic chemicals and other products.

2. Processes

2.1 Raw materials and delivery

The raw materials for use in inorganic chemical manufacture are varied and include solids, liquids and gases.

Deliveries of solid raw materials vary in nature from high volume materials, such as mineral ores, down to low volume, high cost materials such as reaction catalysts.

Liquid raw materials delivered may include fuel and maintenance oils, acids and alkalis, organic solvents (including chlorinated hydrocarbons used in degreasing and cleaning operations) and petrol and diesel for on-site vehicles.

The majority of process and process-related raw materials received on a site arrive by road, rail or sea in bulk quantities. Acids, alkalis and organic solvents are typically delivered by bulk road tanker, with other minor chemicals in drums and intermediate bulk containers (IBCs).

2.2 Transfer of materials on site

Bulk mineral ores are typically transported using conveyor belt systems or other mechanical equipment.

Liquids are typically transferred by pumping to areas of storage or use. Drums and kegs may be either manually or mechanically handled, whereas the larger IBCs are transferred by fork-lift truck.

Within the process and production facilities the handling of raw materials is by a mixture of manual, semi-automatic and automatic operations involving lifting gear, fork-lift trucks, conveyors and pipelines.

3. The chlor-alkali industry

The chlor-alkali industry is concerned with the production of chlorine, hydrochloric acid, sodium hydroxide and, in the past, sodium carbonate.

The industry has made use of three main processes:

Le Blanc process	To produce sodium carbonate; modifications to the process produced chlorine (now mostly obsolete).
Solvay (ammonia-soda) process	To produce sodium carbonate.
Electrolytic process	To produce sodium hydroxide and chlorine.

The 19th Century alkali industry, based on the Le Blanc process, was centred on Tyneside, Merseyside and Clydeside, because mineral supplies were available locally. The advent of the Solvay process encouraged the industry to locate in Cheshire and Teesside so as to be near to natural brinefields. The electrolytic industry developed in established alkali districts in order to take advantage of the existing pattern of ancillary trades and markets.

The alkali industry originally developed to supply the soap and glass industries with sodium carbonate. Most sodium carbonate produced today is consumed by glass manufacture (see Section 9), although a significant amount is also used to make sodium phosphate.

Sodium hydroxide is primarily employed in the manufacture of both inorganic and organic chemicals. It is also used in the manufacture of wood pulp, paper, soap and detergents (see Section 9).

Approximately 30% of United Kingdom chlorine production is used for polyvinyl chloride (PVC) manufacture; smaller amounts are used in paper pulp bleaching and to make inorganic chemicals, chlorinated solvents and other organic compounds.

3.1 Manufacture

3.1.1 Le Blanc process (for sodium carbonate and chlorine)

The first manufacture of synthetic alkali (sodium carbonate) in the United Kingdom using a Le Blanc-type process is attributed to Losh and Company of Walker-on-Tyne in 1823. The Le Blanc process involved the heating of salt (sodium chloride) and sulphuric acid to form 'saltcake' (sodium sulphate). The reaction was accompanied by the production of hydrochloric acid fumes. Saltcake was then heated with coal and calcium carbonate (in the form of chalk or limestone) to produce 'black ash', a mixture of sodium carbonate, calcium sulphide and unreacted coal. The black ash was leached with warm water to extract the soda ash (sodium carbonate) which was then concentrated by evaporation.

The hydrochloric acid fumes from the Le Blanc process caused a major health and environmental hazard. To deal with the problem, Parliament passed the Alkali Act of 1863 to control the industry. The Act, and a growing industrial demand for chlorine, encouraged the development of processes to recover and use by-product hydrochloric acid. The Weldon process was most commonly used. Recovered hydrochloric acid was reacted with manganese dioxide and steam to produce chlorine gas. The chlorine was reacted with slaked lime (calcium hydroxide) to produce bleaching powder (calcium hypochlorite). A still liquor was left behind containing unreacted hydrochloric acid, manganese chloride and residual chlorine which was difficult to dispose of. After 1869, the manganese in the still liquor was usually recovered through reaction with a calcium hydroxide suspension and an air stream to regenerate manganese dioxide in 'Weldon mud'. This process generated further calcium chloride waste. Later, the alternative Deacon process, which generated chlorine by passing hydrochloric acid over a cupric chloride catalyst, was also adopted but to a lesser extent.

The insoluble residue which remained after the leaching of sodium carbonate from black ash in the Le Blanc process, was termed tank waste (or 'gallygoo') and comprised mainly calcium sulphide plus some unburnt coal, coal ash and sodium sulphide. This was generally dumped around the works, where acid fumes reacted with the waste sulphides to produce malodorous hydrogen sulphide gas. After 1887, sulphur was recovered from tank waste by blowing exhaust gases containing carbon dioxide through a waste slurry to convert calcium sulphide to calcium carbonate and hydrogen sulphide; the latter was burnt to yield pure sulphur. An alternative sulphur recovery process was developed, but not widely used, involving the partial oxidation of the waste sulphides to thiosulphates, followed by reaction with waste hydrochloric acid.

Sodium carbonate was converted into a number of useful products in the following ways:

> Sodium bicarbonate was produced by dissolving sodium carbonate in hot water and reacting the solution with carbon dioxide; sodium bicarbonate crystals formed on cooling.
>
> Sodium hydroxide was produced by reacting sodium carbonate with calcium hydroxide.
>
> Sodium hydroxide was reacted with sulphur dioxide to obtain sodium bisulphite.

The requirement for sulphuric acid and slaked lime was met by in-house plants at Le Blanc works. The Le Blanc process survived up until the 1920s because of its ability to produce valuable by-products such as bleaching powder. Integrated works based around the Le Blanc process were eventually superseded by the Solvay (ammonia-soda) process route to sodium carbonate and by electrolytic routes to chlorine.

3.1.2 The Solvay process (for sodium carbonate)

The first successful commercial use of the Solvay (ammonia-soda) process in the United Kingdom was in 1873 by Ludwig Mond and John Brunner at Winnington in Cheshire. The process involves the formation of ammonium bicarbonate in purified concentrated brine by saturating the brine with ammonia and carbon dioxide gases. The ammonium bicarbonate reacts with sodium chloride to form sodium bicarbonate, which is then thermally decomposed to yield sodium carbonate. A small number of plants continue to operate this process in Cheshire.

Brine used in the Solvay process is first purified to precipitate out metals, primarily calcium, magnesium, aluminium and iron, and sulphate by the addition of sodium hydroxide or sodium carbonate and barium chloride. The resulting waste sludge was disposed of in extensive lagoons that characterise districts where the Solvay process has been used. Limestone is heated on site to produce carbon dioxide, using coke, oil or natural gas as fuel. The resulting lime is used to make slaked lime and the carbon dioxide to carbonate the brine. The ammonia requirement of works employing the Solvay process was initially met by ammoniacal liquor from gas works or on-site coal carbonisation facilities. Later, ammonia synthesis plants were developed on, or close to, Solvay works. A small amount of sodium sulphide is also employed in the process.

The Solvay process is more efficient in the use of raw materials than the Le Blanc process and gives a purer product. The thermal decomposition of sodium bicarbonate yields carbon dioxide which is recycled. Ammonia is also recycled by reacting the mother liquor with slaked lime to release ammonia gas, leaving calcium chloride waste.

3.1.3 Electrolytic processes (for sodium hydroxide and chlorine)

Whereas the Solvay process yields chlorine from brine in the form of calcium chloride, a compound of little economic value, the electrolytic process produces elemental chlorine, which is in great demand as a raw material for the chemical industry.

The electrolysis of brine yields chlorine and sodium; the sodium reacts with water to produce hydrogen and a solution of sodium hydroxide. Brine used for electrolysis is purified by the precipitation of metal hydroxides, followed by ion exchange. Two basic forms of cell are used: the diaphragm cell (first developed by James Hargreaves and Thomas Bird of Widnes in 1890) and the mercury cell (first employed by the Castner-Kellner Company at Runcorn in 1897).

The diaphragm cell

Although there are many variants, the diaphragm cell basically consists of a metal or graphite anode separated from a steel screen cathode by an asbestos diaphragm, which restricts the diffusion of product gases between compartments but allows brine to pass through. Chlorine gas is liberated in the anode compartment and sodium hydroxide and hydrogen gas are formed in the cathode compartment. The sodium hydroxide requires purification to remove sodium chloride, sodium chlorate and colloidal iron. The membrane cell, a variant of the diaphragm cell, employs a synthetic, water-impermeable, ion-conducting membrane in place of the asbestos diaphragm.

The mercury cell

When an electric current is passed through the concentrated and purified brine in the mercury cell, the mercury cathode combines with liberated sodium to form an amalgam. The amalgam decomposes with water to yield sodium hydroxide and hydrogen gas, and to regenerate the mercury. Chlorine gas is evolved at the graphite anode. Residual chlorine and some chlorate ions are removed from the spent brine by acidification, degassing, reduction with sodium bisulphite and neutralisation. The brine is then re-saturated with salt, repurified and recycled.

In the past, discharges of brine contaminated with mercury were common. The mercury cell dominated chlorine production until recently, when concern about mercury pollution led to the increased adoption of the membrane cell.

The sodium hydroxide produced by electrolysis is concentrated through evaporation. The chlorine contains impurities such as organic chlorides, mostly of low molecular weight. These can be combusted to form carbon dioxide and hydrochloric acid, which is recovered. The chlorine is dried by cooling (to condense water vapour), then scrubbed with sulphuric acid and liquefied.

Demand for chlorine stimulated the growth of electrolytic processes at the expense of the Le Blanc by-product and the Weldon and Deacon processes. However, though sodium carbonate can be made from sodium hydroxide, electrolytic processes have not entirely supplanted the Solvay process for manufacturing sodium carbonate.

3.1.4 Hydrochloric acid manufacture

In the past, hydrochloric acid was produced as a by-product of the Le Blanc process; it was later manufactured by the reaction of chlorine with hydrogen. However, since 1950, hydrochloric acid has been obtained as a by-product of chlorination processes, and to a lesser extent as a by-product of sodium sulphate manufacture.

3.2 Potential sources of contamination

Former Le Blanc works and the surrounding land are typically characterised by large mounds of tank waste. Sulphides in tank wastes would generally undergo atmospheric oxidation to sulphates, giving the materials a white or light colour. Le Blanc works often utilised a soakaway, free-draining adit or watercourse for disposal of liquid wastes).

Calcium chloride brines from the Solvay process were typically stored in vast lagoons.

Discharges of brine contaminated with mercury from electrolytic processes may have caused contamination of soil, groundwater and surface water.

In addition to waste disposal activities, contamination may also have resulted from accidental releases of raw materials, intermediates and products. Leaching of materials stored in the open air by acidic run-off (resulting from the washout of acid fumes of materials stored in the open air) may also have occurred.

Contamination may extend below the surface as a result of contaminant leaching, transport by rainwater infiltration and the disposal of liquid wastes. Groundwater underlying the site may therefore be contaminated due to the migration of more soluble compounds.

In the past, local off-site disposal of waste material may have occurred.

4. Sulphuric acid works

The largest consumer of sulphuric acid is the chemical industry, which utilises sulphuric acid in the production of both inorganic products (for example phosphate fertilisers, hydrofluoric acid, chromic acid, aluminium sulphate, sodium sulphate) and organic products (for example explosives, isocyanates, plastics, pharmaceuticals). Sulphuric acid is also used in electrical battery manufacture, copper ore leaching and in pulp and paper mills. Significant quantities of the acid are used during the manufacture of pigments, detergents, dyestuffs and synthetic fibres. The acid is used to a lesser degree by the metallurgical industry, for steel pickling, and by petrochemical industries, for alkylation and sulphonation reactions (see Section 9 for relevant profiles).

Sulphuric acid was first manufactured in the United Kingdom in 1736 on a small scale by Joshua Ward in Twickenham, London. Brimstone (natural elemental sulphur) and saltpetre (sodium nitrate) were combusted to yield sulphur trioxide gas which was absorbed in water to form dilute sulphuric acid. After 1746, this process was undertaken in lead chambers, giving rise to the name 'chamber process'. From 1840, the brimstone was substituted in part by sulphur dioxide, produced by roasting pyritic ores ie metal sulphides. After 1870, an alternative source of sulphur was 'spent oxide' from gas works, the ferrous oxide used to purify the gas stream, which was enriched in free sulphur. Recovered nitrogen oxides were recycled by means of a 'Glover tower' after 1859. By about 1890, an alternative acid-making process was in use, the 'contact process', in which sulphur dioxide was reacted with oxygen or air over a platinum catalyst to form sulphur trioxide. Platinum was soon replaced by vanadium pentoxide as the main catalyst.

During the 20th Century, two features have marked the development of the sulphuric acid industry in the United Kingdom, namely the progressive shift from the chamber process to the contact process and the changes in the source of sulphur feedstock. In 1939, only 37% of sulphuric acid was manufactured by the contact process. This figure had increased to over 90% by 1964 and today all sulphuric acid is manufactured using this method.

Prior to 1930, pyrite (iron sulphide ore) was the primary sulphur feedstock, with lesser amounts of spent oxide from gas works, natural sulphur and zinc sulphide concentrate (imported as a zinc source) used. After 1945, almost all new plants used elemental sulphur imported from the United States of America. Restrictions on sulphur exports from this source in 1950 led to the development of anhydrite (anhydrous calcium sulphate) as a source of sulphur. Anhydrite was kilned with coke and either clay or ash to yield sulphur and a clinker which was ground to form cement. Sulphur from oil refineries provided an additional sulphur source. Elemental sulphur and zinc concentrates are the only feedstock in use today. In 1991, 90% of sulphuric acid produced in the United Kingdom was from sulphur, 78% of which was imported.

During the 19th Century, most sulphuric acid was produced either by major users, for example alkali and dyestuffs works, for their own processes or by industries supplying feedstocks, such as gas works and metal smelting plants. Today, sulphuric acid is one of the most widely used commercial chemicals and about 55% of the total United Kingdom production is used at the site of its production. The location of plants has generally been determined by proximity to major markets or raw materials. Dependence on imported sulphur has led to a preponderance of coastal sites, usually adjacent to major ports.

4.1 Manufacture

In the chamber process, sulphur dioxide gas was passed counter-current with a stream of nitro-sulphuric acid in a Glover tower and underwent partial oxidation to sulphur trioxide. These gases were then mixed with nitrogen dioxide gas from an ammonia oxidation unit (which replaced the saltpetre) and were fed into the lead chamber where most of the remaining sulphur dioxide was oxidised to the trioxide and then hydrated to sulphuric acid. Residual nitrogen oxides were recycled to the Glover tower. The chamber process produced a relatively weak acid which was then concentrated.

In the contact process, sulphur dioxide mixed with an excess of dry air is oxidised to the trioxide in a series of fixed vanadium pentoxide catalyst beds. The sulphur trioxide is then absorbed in sulphuric acid. In the 'double contact' process, sulphur trioxide is absorbed from the gas stream between catalyst beds, giving a higher overall conversion rate (99.6%). Although purification of tail gases is unnecessary for the latter process, single absorption plants may require scrubbers (using ammonia, lime, dimethylaniline or sodium sulphate/bisulphate solutions), activated carbon adsorption towers, or oxidation units utilising peroxygen chemicals.

Sulphur dioxide produced for sulphuric acid manufacture by burning elemental sulphur or hydrogen sulphide does not require purification. Sulphide ores (primarily pyrites, but also copper, lead, nickel and zinc materials) can be roasted in rotary kilns, multiple-hearth roasters or fluidised-bed furnaces to yield sulphur dioxide which requires purification to remove catalyst poisons (such as arsenic trioxide) and fly ash. Cyclones and electrostatic precipitators are used to remove particulates. The same technology was applied to clean up the sulphur dioxide produced from anhydrite. Waste concentrated sulphuric acid and acid sludges from oil refining may also be thermally decomposed to yield sulphur dioxide.

4.2 Potential sources of contamination

Contamination may have resulted from accidental releases of materials in the vicinity of the production plant, storage and transfer areas. Contaminants may have been leached from stockpiles of pyrite stored in uncovered areas. Sulphuric acid and a wide range of heavy metals may be found associated with pyritic ores.

Ammonia and its derivatives (nitrites and nitrates) may be found in association with former lead chamber plant sites. Cyanides may be present where spent oxide has been used as a feedstock.

Contamination may arise from the disposal of metal-rich fly ash, acid neutralisation sludges and spent catalysts on site.

5. Nitric acid and ammonia works

Most nitric acid and ammonia are used for the production of fertilisers, such as ammonium nitrate, sodium nitrate, potassium nitrate, ammonium sulphate and urea. Nitric acid is also used to produce adipic acid for nylon manufacture and nitrated organic compounds, for example nitroglycerine and nitrobenzene. Ammonia is also used to produce ammonium chloride, acrylonitrile and a range of amines, amides and nitrates which are intermediates in fibres and plastics manufacture.

The date of the first commercial production of nitric acid in the United Kingdom is uncertain, though it is known that the acid was produced in Birmingham in 1759. The original nitrate feedstock was soil, manure or imported guano. From 1825 to 1918, all United Kingdom nitric acid was manufactured from Chile saltpetre (sodium nitrate) which was reacted with concentrated sulphuric acid to yield nitric acid and sodium sulphate. The Oswalt process, involving the catalysed air oxidation of ammonia to nitric acid, was developed in 1918 and had largely superseded the saltpetre method by 1925. The old process was still in use in some works until 1939.

Ammonia was originally produced solely as a by-product of the coal carbonisation industries. Soon after the First World War a synthetic ammonia works was set up at Billingham, based on the Haber process (see Section 5.1.1).

Historically, the nitric acid industry has been associated with Le Blanc alkali works. It used the sodium sulphate by-product and supplied the sulphuric acid feedstock.

Later plants were associated with the synthetic ammonia works which developed at Flixborough (1937), Mossend (1939), Dowlais (1940), Heysham and Prudhoe (1942), Shell Haven (1959) and Severnside (1963). Ammonia works are commonly associated with oil refineries, which supply hydrogen or hydrogen feedstocks.

5.1 Manufacture

5.1.1 Ammonia

In the Haber process, a purified 3:1 mixture of hydrogen and nitrogen is reacted at elevated temperature and pressure over an iron oxide catalyst to form ammonia.

Nitrogen is obtained for the process by the liquefaction of air or by using the producer gas reaction, which involves the combustion of coal or coke in a restricted air supply to yield a mixture of carbon monoxide and nitrogen. Alternatively, nitrogen can be obtained by burning out the oxygen in air with hydrogen.

Hydrogen is produced by brine electrolysis or by steam reforming natural gas, oil refinery gas or naphtha. In the past water gas, a mixture of hydrogen and carbon oxides produced by passing steam over red hot coke, was used. The carbon monoxide and steam may be further reacted over a metal oxide catalyst, normally iron, chromium, cobalt, molybdenum, copper or zinc oxide, to form carbon dioxide and hydrogen.

Steam reforming involves passing a hydrocarbon feedstock, mixed with steam, over a nickel catalyst. Impurities such as carbon oxides are removed from the reagent gas streams by treatment with ethanolamine, potassium carbonate (using sodium metavanadate or arsenic trioxide as an activator), propylene carbonate or the *Sulfinol* process.

The *Sulfinol* process (patented by Shell) uses a solvent, consisting of sulpholane, diisopropanolamine and water, for removing carbon dioxide.

Final purification of the hydrogen was achieved in the past by washing with ammoniacal cuprous formate. The purification methods now used are hydrogenation and condensation and absorption of methane using a nickel catalyst and zeolite absorbent.

Promoters, which include oxides of potassium, aluminium, calcium and silicon, are added to the catalyst used in the Haber process. The catalyst has a lifetime of up to ten years but is poisoned by phosphorous, arsenic, sulphur and carbon oxides.

5.1.2 Nitric acid

Anhydrous ammonia and air are reacted at elevated temperature and pressure over a platinum-rhodium catalyst to produce nitric oxide. This is further oxidised to nitrogen dioxide which is hydrated to form nitric acid.

The nitric acid is then concentrated by dehydration using concentrated sulphuric acid or magnesium nitrate. Exhaust gases from nitric acid production require purification by scrubbing with ammonia, sodium hydroxide or urea solutions, catalytic reduction with ammonia, reductive post-combustion with various fuels or adsorption on molecular sieves.

5.2 Potential sources of contamination

Nitrogen compounds may occur around ammonia and nitric acid production plants.

Sulphur compounds are most likely to be encountered on sites operating before 1925, although they may be associated with spent catalysts or reagent gas purification wastes.

Alkalis used to neutralised acid wastes may be found in waste disposal areas; these areas may also contain heavy metals from spent catalysts.

Coal or coke residues may be found in the vicinity of former producer gas or water gas plants.

6. Phosphoric acid works

Phosphoric acid was first made as an intermediate product during the manufacture of phosphorous for match making by Albright and Sturge of Birmingham in 1884. Bone ash, and later phosphorous ore (fluorapatite), treated with sulphuric acid were found to yield phosphoric acid.

The use of the fluorapatite, which contains both calcium phosphate and calcium fluoride, has been the basis of the 'wet' and 'dry' processes that have been employed to manufacture phosphoric acid this century. The ore was usually imported from Senegal, Morocco and Florida.

The dry process was used to produce a high purity product for the food and pharmaceuticals industries. At the turn of the century, plants were based at Albury, Widnes and Kirkby. The lifetime of each plant was approximately 10 to 15 years, with an output of 10 000 tonnes per annum. A plant at Portishead was operational in the 1950s and 1960s. The last operational dry process plant was at Oldbury, in the West Midlands.

Historically, the wet process industry was located at Teesside, Humberside, Whitehaven and Avonmouth. Currently, the only working wet process plant is at Thorton, Merseyside. Typically, plants could produce 50 000 to 100 000 tonnes per annum. Most wet phosphoric acid is used in fertiliser production. The remainder is used in soaps and detergents (as sodium tripolyphosphate), metal preparation, nylon production, food additives, pharmaceuticals and water treatment chemicals (see Section 9).

6.1 Manufacture

The dry process
The dry process involved the heating of fluorapatite, coke and sand (silica) in an electric furnace to produce elemental phosphorous vapour and carbon monoxide. Calcium fluoride, fluorosilicates and silicon tetrafluoride were formed in the furnace, as well as calcium silicate slag with some iron-phosphorous content. The solid impurities and by-products were run off from the furnace; the carbon monoxide and phosphorous vapour from the furnace gas were oxidised to carbon dioxide and phosphorous pentoxide. The phosphorous pentoxide was then absorbed by water in a packed tower to form phosphoric acid. Impurities in the phosphoric acid

arising from the original ore were removed by reaction with hydrogen sulphide (to remove arsenic trisulphide), with sulphuric acid (to remove calcium sulphate) and with powdered silica (to remove hydrofluoric acid). The pure acid was then filtered.

The wet process
The wet process involves the digestion of ground fluorapatite by a sulphuric/phosphoric acid solution in multiple tanks with vigorous agitation. The resulting calcium sulphate residue is filtered, washed and slurried to a settling lagoon. The acid is concentrated by evaporation. The fluoride contained in the fluorapatite is either removed as silicon tetrafluoride, after reaction with silica and absorption in scrubbers as aqueous hexafluorosilicic acid, or largely removed with the calcium sulphate as sparingly soluble sodium hexafluorosilicate. The wet acid is very impure and concentrating it causes the deposition of insoluble impurities as a sediment or 'slime'. Further purification is undertaken for specific purposes, particularly for high purity food grade phosphoric acid. This is achieved by precipitation of copper sulphide, arsenic sulphides and barium sulphate and by liquid-liquid extraction using alcohols, tributyl phosphate or isopropyl ether.

6.2 Potential sources of contamination

Contamination may have occurred from the mineral fluorapatite which may contain traces of uranium oxide. Fugitive fluoride emissions from process plant, particularly grinding operations, may have caused widespread low-level contamination extending beyond the site boundary.

Contamination is most likely to occur at the locations of settling ponds and waste disposal sites. Owing to their toxic and flammable nature, heavy metals and phosphorous residues were disposed of either in on-site or local clay-lined holes. Elemental phosphorous may exist in buried dry process wastes and can spontaneously combust following exposure to dry air. Ammonia, copper, nitrates and sulphites are associated with wet process waste.

The wet process produces a large volume of gypsum waste which typically contains low levels of heavy metals. In the past, coastal sites would have discharged this to the sea; inland sites would have disposed to on-site or local clay-lined holes. Removal of this waste from the reaction vessels may have resulted in minor acid spillages, which may result in localised areas of ground with a low pH.

7. Waste management

The attitude to waste management has undergone considerable change during the lifetime of the industry. The increased costs of implementing environmental legislation and disposing of waste, and the high cost of special raw materials, such as catalysts, has prompted a move towards recycling and waste minimisation where possible.

Wastes can be stored in a variety of drums or vessels in specially designed compounds or, in the past, in open areas in direct contact with the soil. Typically, they are collected and stored until sufficient material is amassed for cost effective disposal. Disposal is normally via an outside contractor to a licensed landfill.

Manufacturing plants generally have a wash-down policy on roads to suppress dust; the run off which is produced may either be discharged directly to a river or to the foul sewer where it passes to a wastewater treatment plant.

Waste material may have previously been dumped at sea or disposed of to on-site landfills and tip areas.

8. Contamination

The contaminants on a site will largely depend on the history of the site and on the range of materials used there. Potential contaminants are listed in the Annex and the probable locations on site of the main groups of contaminants are shown in Tables 1-6. It is most unlikely that any one site will contain all of the contaminants listed. It is recommended that an appropriate site investigation is carried out to determine the exact nature of the contamination associated with individual sites.

8.1 Factors affecting contamination

Contamination is likely to have arisen as a result of previous on-site disposal practices or by spillage and leakages from tanks, pipework and drainage systems. Hazardous waste storage areas, particularly where these are outside and poorly contained, as well as bulk storage and transfer areas, may also give rise to soil contamination.

Past, rather than current, practices are likely to have been primarily responsible for any legacy of ground and groundwater contamination. Chemical storage was generally less well controlled in the past, and it was common practice for any spills or untreated effluents to be washed into surface water drains and localised disposal pits (soakaways). Contaminated dust and floor sweepings may have been deposited in pits on site. In addition, dilute and disperse landfills were operated within some large sites and these could be a significant source of contamination.

Asbestos, which was used in pipe lagging, insulation, cladding or roofing of buildings, may also give rise to contamination if the plant was refitted or demolished.

Electrical transformers or capacitors in electricity substations may have used polychlorinated biphenyls (PCBs) as dielectric fluids and these may have caused contamination during refilling or dismantling.

There is the potential for fuel oils used for on-site power generation to cause contamination if there has been leakage or spillage in the vicinity of storage tanks and pipework.

8.2 Migration and persistence of contaminants

8.2.1 Metals

The highest level of contamination is likely to be found closest to the surface of the ground and a general decrease in concentration with depth would be expected. Metals have varying degrees of solubility, depending upon the nature of the associated anion. Oxides and sulphides have low solubilities and their concentration is likely to decrease with depth. Metal sulphates and nitrates are significantly soluble and mobile in soil.

The movement of metals through the soil is significantly retarded by the presence of clay minerals and organic matter. The solubility of some metals (for example copper, zinc and lead) may increase under acidic conditions. 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 pHs.

8.2.2 Acids and alkalis

Mineral acids migrate within soil-water in the dissociated form, ie as the hydrogen ion and the corresponding anion (for example nitrate or sulphate). The buffering capacity of most soils tends to neutralise slight acidity. Dissolved nitrate and sulphate migrate freely through the soil.

Acid spillage near buildings may affect the integrity of concrete and cement-based construction materials.

8.2.3 Inorganic substances

The migration of inorganic contaminants in moist soil and water is closely related to their aqueous solubility, which may be enhanced by an alteration in soil pH.

Sodium and calcium chlorates and nitrites, all metallic nitrates and most sulphates (excepting those of lead, calcium and barium) are extremely water-soluble. The presence of sulphates in the ground may affect the integrity of concrete and cement-based building materials. Sulphides generally have very little or no aqueous solubility. Barium chloride and most metal chlorides are water soluble, with the exception of silver and lead chlorides. Most ammonium salts are water-soluble and are very similar in chemical properties to the alkali metal salts.

Simple alkali metal cyanides are soluble. Aqueous solutions of cyanides hydrolyse slowly to the carbonate and ammonia, the timescale depending on temperature and the presence of other chemicals. However, the slow breakdown of complex cyanides in the soil may act as a long-term source of free cyanide contamination.

8.2.4 Organic substances

Hydrocarbon fuel oils released at the surface or leaking from an underground structure may flow down through the ground. Some hydrocarbons are adsorbed on to soil particles and are retained in soil pores. Generally, the higher the natural organic matter and clay content within the soil, the greater the adsorption of organic compounds and the lower their mobility. Conversely, the greatest migration of contaminants will occur in coarse-grained sands and gravels with little organic content. On encountering groundwater the liquid will normally spread out on the surface of the water and migrate laterally, preferentially in the direction of groundwater flow.

Even though fuel oils are sparingly soluble in water, the small amounts that do dissolve can adversely affect water supplies. The less soluble components of fuel oils which become adsorbed on to soil organic matter will provide an on-going source of water pollution by continuing to desorb into the soil-water.

Biodegradation processes in soils can be influenced by a number of factors, namely moisture content, oxygen concentration and pH, acting separately or in combination. For example, low moisture content reduces microbiological activity, while high moisture content can reduce oxygen penetration and possibly lead to anaerobic soil conditions. Such conditions enhance the biodegradation of some materials, eg chlorinated compounds, while aerobic conditions are needed to biodegrade many oils. Also, low pHs tend to reduce the bacterial population and encourage fungal activity; at pHs lower than 5 microbiological activity is much reduced. The presence of heavy metals also inhibits micro-organisms. As a result of these factors, at high concentrations in soil, even relatively non-persistent compounds may not biodegrade readily.

Polychlorinated biphenyls (PCBs) have low aqueous solubility and are highly persistent. They are fat-soluble and tend to accumulate in food chains.

8.2.5 Other factors

Wind dispersion of contaminated soil may be a further transport mechanism where the surface is grossly contaminated with, for example, asbestos. However, when compared with other sources of contamination this is usually a minor factor.

The occurrence of fires on site, and the consequent flow of fire-fighting water, could transport pollutants over a wide area.

Asbestos is neither soluble nor biodegradable and persists in the soil.

9. Sources of further information

9.1 Organisations

For information concerning the inorganic chemicals manufacturing industry in the United Kingdom the following organisations should be consulted:

The Chemical Industries Association
Limited Kings Building
Smith Square
London
SW1P 3JJ

The National Sulphuric Acid Association Limited
140 Park Lane
London
W1Y 4DT

The Society of Chemical Industry
14/15 Belgrave Square
London
SW1X 8PS

9.2 Sources of information concerning the activities described in this profile

Campbell W A. *The chemical industry.* Longman, 1971.

Hardie D W F and Davidson Pratt J. *A history of the modern British chemical industry.* Pergamon Press, 1969.

Heaton C A. *The chemical industry.* Blackie, 1986.

Kent J A (Editor). *Reigel's handbook of industrial chemistry.* Ninth Edition, Chapters 10-12, 14 and 28. Van Nostrand Reinhold Company, 1992.

Warner K. *Chemical foundations: the alkali industry in Britain to 1926.* Clarendon Press, 1980.

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 inorganic chemicals manufacturing industry can be obtained from the Central Government statistics, held principally by the Guildhall Library, Aldermanbury, London and the 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).

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

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

9.3 Related DOE Industry Profiles

Ceramics, cement and asphalt manufacturing works
Chemical works: coatings (paints and priting inks) manufacturing works
Chemical works: fertiliser manufacturing works
Chemical works: organic chemicals manufacturing works
Chemical works: pharmaceuticals manufacturing works
Chemical works: soap and detergent manufacturing works
Engineering works: electrial and electronic equipment manufacturing works (including works manufacturing equipment containing PCBs)
Gas works, coke works and other coal carbonisation plants
Oil refineries and bulk storage of crude oil and petroleum products
Pulp and paper manufacturing works
Textile works and dye works
Profile of miscellaneous industries

9.4 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.** *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, 1993.
>
> **Her Majesty's Inspectorate of Pollution.** *Processes for the manufacture or recovery of nitric acid and processes involving the manufacture or release of acid-forming oxides of nitrogen.* Chief Inspector's Guidance to Inspectors. Process Guidance Note IPR 4/11. London, HMSO, 1993.
>
> **Her Majesty's Inspectorate of Pollution.** *Processes for the sulphonation or nitration of organic chemicals.* Chief Inspector's Guidance to Inspectors. Process Guidance Note IPR 4/12. London, HMSO, 1993.
>
> **Her Majesty's Inspectorate of Pollution.** *Processes for the manufacture of, or which use or release halogens, mixed halogen compounds or oxohalocompounds.* Chief Inspector's Guidance to Inspectors. Process Guidance Note IPR 4/13. London, HMSO, 1993.
>
> **Her Majesty's Inspectorate of Pollution.** *Processes for the manufacture of, or which use or release halides or any of their acids.* Chief Inspector's Guidance to Inspectors. Process Guidance Note IPR 4/14. London, HMSO, 1993.
>
> **Her Majesty's Inspectorate of Pollution.** *Bulk storage installations.* Chief Inspector's Guidance to Inspectors. Process Guidance Note IPR 4/17. London, HMSO, 1993.

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:

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

9.5 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 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.

The chlor-alkali industry - Le Blanc process

Inorganic compounds	chlorides sulphates sulphides
Metals, metalloids and their compounds	metals associated with coal ash eg aluminium antimony arsenic boron cadmium chromium copper cobalt lead manganese molybdenum nickel selenium tin vanadium zinc
	manganese/copper (from Weldon and Deacon processes)
Alkalis	calcium oxide (lime) residues sodium hydroxide sodium carbonate
Acids	hydrochloric sulphuric
Organic compounds	fuel oil polychlorinated biphenyls (PCBs)
Coal/coke residues	polycyclic aromatic hydrocarbons (PAHs)
Asbestos	

The chlor-alkali industry - Solvay (ammonia-soda) process

Inorganic compounds	ammonium compounds and ammoniacal liquor chlorides nitrites nitrates sulphates sulphides
Alkalis	calcium oxide (lime) residues sodium hydroxide sodium carbonate
Acids	hydrochloric sulphuric
Metals, metalloids and their compounds	aluminium barium iron
Organic compounds	fuel oil polychlorinated biphenyls (PCBs)
Coal/coke residues	polycyclic aromatic hydrocarbons (PAHs)
Asbestos	

The chlor-alkali industry - electrolytic processes

Inorganic compounds	ammonium compounds chlorides chlorates nitrates nitrites sulphates sulphides
Alkalis	calcium oxide (lime) residues sodium hydroxide sodium carbonate
Acids	hydrochloric sulphuric
Metals, metalloids and their compounds	antimony arsenic bismuth cadmium copper lead mercury silver tin

Organic compounds	low molecular weight organic chlorides fuel oil polychlorinated biphenyls (PCBs)
Asbestos	

Sulphuric acid works

Acids	sulphuric
Inorganic elements and compounds	cyanides (complex and free) ammonium compounds nitrites nitrates sulphates sulphides sulphur
Metals, metalloids and their compounds	arsenic copper lead nickel platinum vanadium zinc other heavy metals associated with pyritic ores
Alkalis	sodium hydroxide sodium carbonate calcium oxide (lime) residues
Organic compounds	dimethylaniline fuel oil polychlorinated biphenyls (PCBs)
Asbestos	

Ammonia and nitric acid works

Acids	nitric sulphuric
Inorganic elements and compounds	ammonium compounds nitrites nitrates phosphorous sulphates sulphides sulphur
Alkalis	calcium oxide (lime) residues potassium carbonate sodium hydroxide

Metals, metalloids and their compounds	aluminium arsenic chromium cobalt copper iron molybdenum nickel rhodium vanadium eg as sodium metavanadate zinc
Organic compounds	alkanolamines eg ethanolamine ammoniacal cuprous formate diisopropanolamine formates fuel oil polychlorinated biphenyls (PCBs) sulpholane
Coal/coke	polycyclic aromatic hydrocarbons (PAHs)
Asbestos	

Phosphoric acid works

Acids	phosphoric sulphuric
Inorganic compounds	ammonium compounds fluorides nitrates phosphorous phosphates sulphates sulphides sulphites
Alkalis	calcium oxide (lime) residues sodium hydroxide
Metal, metalloids and their compounds	associated with coke ash and fluoroapatite dusts eg arsenic barium cadmium copper uranium oxide (from fluorapatite)
Organic compounds	fuel oil polychlorinated biphenyls (PCBs) tributyl phosphate
Asbestos	

Table 1 Main groups of contaminants and their probable locations

Chemical works: inorganic chemicals manufacturing works - Le Blanc process

Contaminants		Location						
Main groups	**Sub-groups**	**Building fabric**	**Process areas**	**Tanks, pipework and pumps**	**Product storage**	**Waste storage/on-site disposal including lagoons and soakaways**	**Fuel storage**	**Electricity substations and transformers**
Metal and metalloid compounds						▨		
Inorganic compounds	chlorides		▨	▨		▨		
	sulphates		▨	▨				
	sulphides		▨	▨		▨		
Acids	sulphuric, hydrochloric		▨	▨	▨			
Alkalis			▨	▨	▨	▨		
Asbestos		▨	▨	▨		▨		
Organic compounds	fuel oil			▨			▨	
	polychlorinated biphenyls (PCBs)							▨
Other	coal/coke residues					▨		

Shaded boxes indicate areas where contamination is most likely to occur.

Table 2 Main groups of contaminants and their probable locations

Chemical works: inorganic chemicals manufacturing works - Solvay process

Main groups of contaminants	**Location**						
	Building fabric	**Process areas**	**Tanks, pipework and pumps**	**Product storage**	**Waste storage/on-site disposal including lagoons and soakaways**	**Fuel storage**	**Electricity substations and transformers**
Metal and metalloid compounds					▨		
Inorganic compounds		▨	▨		▨		
Alkalis		▨	▨	▨	▨		
Asbestos	▨		▨		▨		
Fuel oils			▨			▨	
Polychlorinated biphenyls (PCBs)							▨
Coal/coke residues					▨		

Shaded boxes indicate areas where contamination is most likely to occur.

Table 3 Main groups of contaminants and their probable locations

Chemical works: inorganic chemicals manufacturing works - electrolytic processes

Main groups of contaminants	Location						
	Building fabric	Process areas	Tanks, pipework and pumps	Product storage	Waste storage/on-site disposal including lagoons and soakaways	Fuel storage	Electricity substations and transformers
Metal and metalloid compounds		▨	▨		▨		
Inorganic compounds		▨	▨				
Acids		▨	▨	▨			
Alkalis		▨	▨	▨			
Asbestos	▨		▨		▨		
Fuel oil			▨			▨	
Polychlorinated biphenyls (PCBs)							▨

Shaded boxes indicate areas where contamination is most likely to occur.

Table 4 Main groups of contaminants and their probable locations

Chemical works: inorganic chemicals manufacturing works - sulphuric acid works

Contaminants		Location						
Main groups	**Sub-group**	**Building fabric**	**Process areas**	**Tanks, pipework and pumps**	**Product storage**	**Waste storage/on-site disposal including lagoons and soakaways**	**Fuel storage**	**Electricity substations and transformers**
Metal and metalloid compounds						■		
Inorganic elements and compounds	sulphates sulphides sulphur		■	■		■		
	cyanides[1]					■		
	ammonia nitrites nitrates[2]		■					
Acids	sulphuric		■	■	■	■		
Alkalis								
Asbestos		■		■		■		
Organic compounds	fuel oil			■			■	
	polychlorinated biphenyls (PCBs)							■

[1] If spent oxide has been used as a feedstock

[2] Chamber process only

Shaded boxes indicate areas where contamination is most likely to occur.

Table 5 Main groups of contaminants and their probable locations

Chemical works: inorganic chemicals manufacturing works - nitric acid and ammonia works

Contaminants		Location							
Main groups	**Sub-group**	**Building fabric**	**Process areas**	**Tanks, pipework and pumps**	**Product storage**	**Waste storage/on-site disposal including lagoons and soakaways**	**Producer gas/water gas plants**	**Fuel storage**	**Electricity substations and transformers**
Metal and metalloid compounds						▨			
Inorganic elements and compounds	ammonia nitrites nitrates					▨			
	suphates sulphides sulphur[1]					▨			
Acids	nitric		▨	▨	▨	▨			
	sulphuric		▨	▨		▨			
Alkalis						▨			
Asbestos		▨				▨			
Organic compounds	alkanolamines		▨						
	fuel oil			▨				▨	
	polychlorinated biphenyls (PCBs)								▨
Other	coal/coke residues						▨		

[1] Most likely on sites operating before 1925, but may be associated with reagent gas purification.

Shaded boxes indicate areas where contamination is most likely to occur.

Table 6 Main groups of contaminants and their probable locations

Chemical works: inorganic chemicals manufacturing works - phosphoric acid works

Contaminants		Location						
Main groups	**Sub-group**	**Building fabric**	**Process areas**	**Tanks, pipework and pumps**	**Product storage**	**Waste storage/on-site disposal including lagoons and soakaways**	**Fuel storage**	**Electricity substations and transformers**
Metal and metalloid compounds	arsenic, barium, cadmium		▨			▨		
	uranium					▨		
Inorganic elements and compounds	phosphorous, phosphates					▨		
	fluorides		▨			▨		
	sulphates, sulphides					▨		
Acids	phosphoric		▨	▨	▨	▨		
	sulphuric		▨	▨		▨		
Alkalis	calcium oxide, sodium hydroxide			▨		▨		
Asbestos		▨		▨		▨		
Organic compounds	fuel oils			▨			▨	
	polychlorinated biphenyls (PCBs)							▨

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

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