



## TECHNICAL AND ECONOMIC REVIEW OF CEMENT AND LIME PROCESS

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The results of this work will be used in the formulation of Environment Agency policy but views expressed in this report do not necessarily represent Environment Agency policy.

**TECHNICAL AND ECONOMIC REVIEW OF  
CEMENT AND LIME PROCESSES**

*A Report to the Environment Agency*

August 1996

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**EXECUTIVE SUMMARY**

The aims of this study are to examine the technical options for controlling releases from cement and lime processes and their respective costs. The study also assesses the economic situation of the cement and lime industries and the ability of these industries to bear the costs of moving from typical release levels towards the achievable release level for a new process.

The technical scope of the study is to establish and assess:

- i) the pollutants emitted from the process;
- ii) the environmental impact of the pollutants released;
- iii) the abatement techniques available.

The main pollutants from both cement and lime processes are releases to air of: particulates,  $\text{NO}_x$ ,  $\text{SO}_2$  and  $\text{CO}_2$ . Other pollutants such as dioxins and heavy metals are also present, but in small quantities. The emissions and environmental impacts were considered on a near field, far field, and global basis. For both industries the near field impacts were found to be more significant than the far field and global impacts.

While emissions to air from lime kilns are similar to those from cement kilns, there are a number of differences:

- cement kilns have a higher  $\text{NO}_x$  production due to a higher process temperature;
- cement kilns have higher particulate emissions;
- the dust produced from the lime process is finer and more alkaline;
- lime kilns have a greater potential to produce and emit dioxins than cement kilns - this is due to their lower process temperature.

Significant near field environmental improvement can be achieved by reducing fugitive emissions of dust. The BAT for doing this is the rigorous application of conventional dust control measures and general good housekeeping.

$\text{SO}_2$  reduction is achievable by selective quarrying (this will largely depend on quarry geology and quarry management) and, where applicable, by recirculating some of the calcined material with the feed for the cement process and some lime with the feed for the lime process. The industry has tried different variations of the lime injection concept, including injection of external lime, with varying degrees of success. This concept needs to be explored and developed within the UK.

$\text{NO}_x$  reduction is possible by adopting the dry process (in the case of cement manufacture) or by process modification to avoid high temperatures and excess air. For dry cement processes, the concept of the 3R Process, which is similar to the existing pre-calciner, can be adopted.

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Heavy metal and dioxins are best reduced by controlling dust emissions and maintaining a low ES temperature to reduce dioxin reformation.

Whilst cement and lime processes use similar production technology and require similar abatement techniques, the implications of moving towards the best available techniques (BAT) for the two industries require separate consideration.

The UK cement industry operates in a highly competitive international market, and this has a major impact on the ability of firms to afford new pollution control systems. Domestic UK prices are effectively capped by the prices of imports. Given this restriction, the ability of the UK companies to afford additional pollution control costs is limited to the reduction in return on capital that the companies concerned can sustain without significantly affecting investment decisions. This is estimated at a net cost of around £1/per tonne of cement produced.

The lime industry operates in a different but nevertheless competitive market. Competition is derived more from substitute products, than threats from imports. Consequently the opportunity for lime producers to pass on additional costs is on the whole limited, although in some niche applications, such as chemicals manufacture, which are less exposed to pressures from substitutes it may be possible to pass on some of the additional cost. Overall it is considered that all lime producers should be able to afford to up-grade emission controls to BAT standards for particulates.



## **1. BAT ASSESSMENT FOR CEMENT AND LIME INDUSTRIES**

### **1.1 Background**

This report has been prepared for HMIP by ECOTEC Research and Consulting Limited in association with AEA Technology, under contract HMIP/CPR2/41/1/97. ECOTEC were responsible for managing the project and carrying out the economic analysis, with AEA Technology contributing the technical review. This study on cement and lime processes comprises one of four reports prepared for HMIP within the Minerals Processing Sector. The other three reports are : Asbestos Processes, Frit and Non-asbestos Mineral Fibre Processes, and Ceramic Processes. This report presents the findings of a worldwide review of cement and lime processes, to assist HMIP Inspectors in their determination of the best available techniques not entailing excessive cost (BATNEEC) for individual process authorisations in the sector. However, it must be emphasised that the situation for a specific plant can only be determined by the Inspector at the time when the authorisation is sought.

The study examines the technical options for controlling releases from these processes and their respective costs, as well as the economic situation of the industry and the ability of the industry to bear the costs of moving from typical release levels towards the achievable release level for a new process.

### **1.2 Report Scope**

The scope of the study covers all cement and lime manufacturing and associated processes described in Section 3.1 of the Environmental Protection (Prescribed Processes and Substances) Regulation 1991.

### **1.3 Report Objectives**

The overall purpose of the report is to provide a worldwide technical and economic review of available techniques for controlling releases from cement and lime processes. The specific aims of the study are to:

- review the proven performance of alternative control techniques, assessing their availability, effectiveness, applicability, potential operating difficulties and costs; and their position relative to BPEO;
- recommend BAT for cement and lime processes;
- highlight other developments which are likely to influence the environmental performance of the sector;

- provide a detailed economic assessment of the industry in order to assess the ability of firms to afford improved environmental controls.

Information used in the study has been obtained from various sources. These include the HMIP Public Register for prescribed processes, site visits and interviews with industry representatives; (both in the UK and overseas) the British Cement Association (BCA); the British Lime Association (BLA) and technical journals. Where appropriate, information has been presented in the report in a general non-attributable way, so as to avoid infringing agreements on confidentiality between the consultants and information providers.

#### **1.4 Report Structure**

The remainder of the report is structured as follows:

- Section 2 assesses the techniques to control releases from cement processes. The main environmental impacts are described together with the techniques for their control, and the associated costs and economic impacts.
- Section 3 assesses the techniques to control releases from lime processes using the same approach.
- Section 4 draws together the key conclusions of the research and considers the implications for the sector of moving towards the implementation of BAT.
- Appendices A, B and C summarise the main environmental impacts of cement and lime processes and profile the techniques for their control.

## 2. CEMENT PROCESSES

### 2.1 The Sector

#### 2.1.1 Sector Description

The statistics in the following discussion are based on the McLellan Report "Waste Combustion in Cement Kilns" (McLellan, 1995). The main companies operating in the UK are Blue Circle, Rugby, and Castle. The total production capacity is 40,770 tonnes of clinker per day and the respective shares of each of these companies are 54%, 20%, and 26%. The market shares are approximately: Blue Circle (49%), Rugby (20%), Castle (22%), and imports (9%).

The companies, locations of the plant, and the capacity are summarized in Table 2.1. More detailed information is given in Appendix B.1.

Cement plants are highly capital intensive with high operating costs. Full utilization of their production capacity is therefore required in order to be economically viable. Consequently any cut in production will adversely affect the profitability of the industry.

**TABLE 2.1 : SUMMARY OF UK CEMENT CLINKER PRODUCTION**

Company	Plant Locations	Total Capacity (te/day)
Blue Circle	Cauldon, Dunbar, Aberthaw, Hope, Weardale, Northfleet, Masons, Cookstown, Pymstock, Westbury	22,200
Rugby	South Ferriby, Rochester, Southam, Barrington, Chinnor, Rugby	8,160
Castle	Ketton, Ribblesdale, Padeswood	10,410

#### 2.1.2 Process Description

The basic chemistry of the cement manufacturing process is first a decomposition of calcium carbonate by heating at about 800°C to leave calcium oxide (lime) and liberate carbon dioxide (CO<sub>2</sub>) as a gas; this process is known as calcination. This is followed by the clinkerization (burning) process in which the calcium oxide reacts at high temperature (typically 1400-1500°C) with silica, alumina, and ferrous oxide to form the silicates, aluminates, and ferrites of calcium which comprise the clinker. The clinker produced is then ground or milled to produce cement clinker.

Naturally occurring calcareous deposits such as limestone and chalk provide the source for calcium carbonate and argillaceous deposits such as clay, shale, and slate provide the alumina, silica, and some iron oxide. The principal raw materials are therefore limestone, chalk, clay, and shales; however other raw materials such as sand, iron oxide, and bauxite may also be required to adjust the chemical composition of the mix. Power station ash, blast furnace slag, and process residues can also be used as partial replacements for the primary raw materials depending on their chemical suitability.

**TABLE 2.2 : LIST OF ALTERNATIVE FUELS**

liquid waste fuels	tar distillation residues used oil petrochemical waste paint waste	chemical wastes waste solvents wax suspensions asphalt slurry oil sludge
solid waste fuels	paper waste pulp sludge petroleum coke plastic residues domestic refuse refuse derived fuel oil-bearing earths	rubber residues used tyres battery cases wood waste rice chaff nut shells sewage sludge
gaseous waste	landfill gas	pyrolysis gas

Various fuels can be used to provide the heat required for the process; these have included coal, petroleum coke, oil, and gas. However, the high temperatures and long residence times required for this process make the use of a wide variety of less expensive alternative fuels possible; these are summarized in Table 2.2. Coal and petroleum coke are pulverized in a mill before being fed to the burners with air for combustion. Various wastes can also be burnt in the cement kilns as fuel supplements. A high proportion of the ash residue from the fuels will be incorporated into the clinker. This is because the ash is derived from shales associated with coal deposits and therefore contains silica, alumina, and iron oxides. This needs to be allowed for in calculating the raw material proportion and so it is highly desirable to use fuel with a consistent - though not necessarily low - ash content. The same applies to other raw materials whose impurities need to be known and accounted for in the blending to produce a product with the specified properties.

Cement manufacture comprises three basic phases: the raw meal preparation, the kiln process, and clinker grinding. These are discussed in turn.

### Raw Meal Preparation

Here the raw materials are finely ground and mixed together to form a homogenous blend. The raw meal can be in various forms:

- i) a slurry containing 40% moisture
- ii) a filter cake or nodules produced by adding water to dry raw meal powder
- iii) dry powder

This material is then fed to a kiln for calcination.

### Kiln Process

Various kiln processes have been developed to accommodate the different raw materials properties such as moisture, grindability, and mineralogy as well as chemistry. In the UK clinker is made by 3 main kiln process routes:

- i) the **wet process** in which the slurry is fed to a long kiln
- ii) Lepol Grate process which can be further sub-divided:
  - a) **semi-dry** process in which water is added to homogenized raw meal powder to form nodules to feed to the travelling grate preheater;
  - b) **semi-wet** process in which filter cake extrusions are fed to the travelling grate preheater;
- iii) the **dry process** in which homogenized raw meal powder is fed to the kiln system - a cyclone preheater is normally included.

Schematic diagrams of these process are shown in Figures 2.1 to 2.4. The percentages of the total clinker produced in the UK by each process are as follows: dry - 49%; semi-dry/semi-wet - 30%; and wet - 21% (McLellan, 1995). Owing to the lower overall specific energy consumption of the dry processes, there has been a move towards these processes away from the wet techniques. Each of these processes has differing impacts on the environment which are discussed in Section 2.2.

All kiln systems have the same distinct sequence of operations to perform irrespective of the type of process:

- i) drying of materials - to remove moisture;
- ii) calcination - to remove carbon dioxide from calcium carbonate to leave calcium oxide;
- iii) clinkerization - to combine the calcium oxide and other added oxides proportionally to form the calcium silicates, aluminates, and ferrites
- iv) cooling - to 'fix' the compound compositions.

FIGURE 2.1 : WET KILN : SCHEMATIC DIAGRAM OF PROCESS

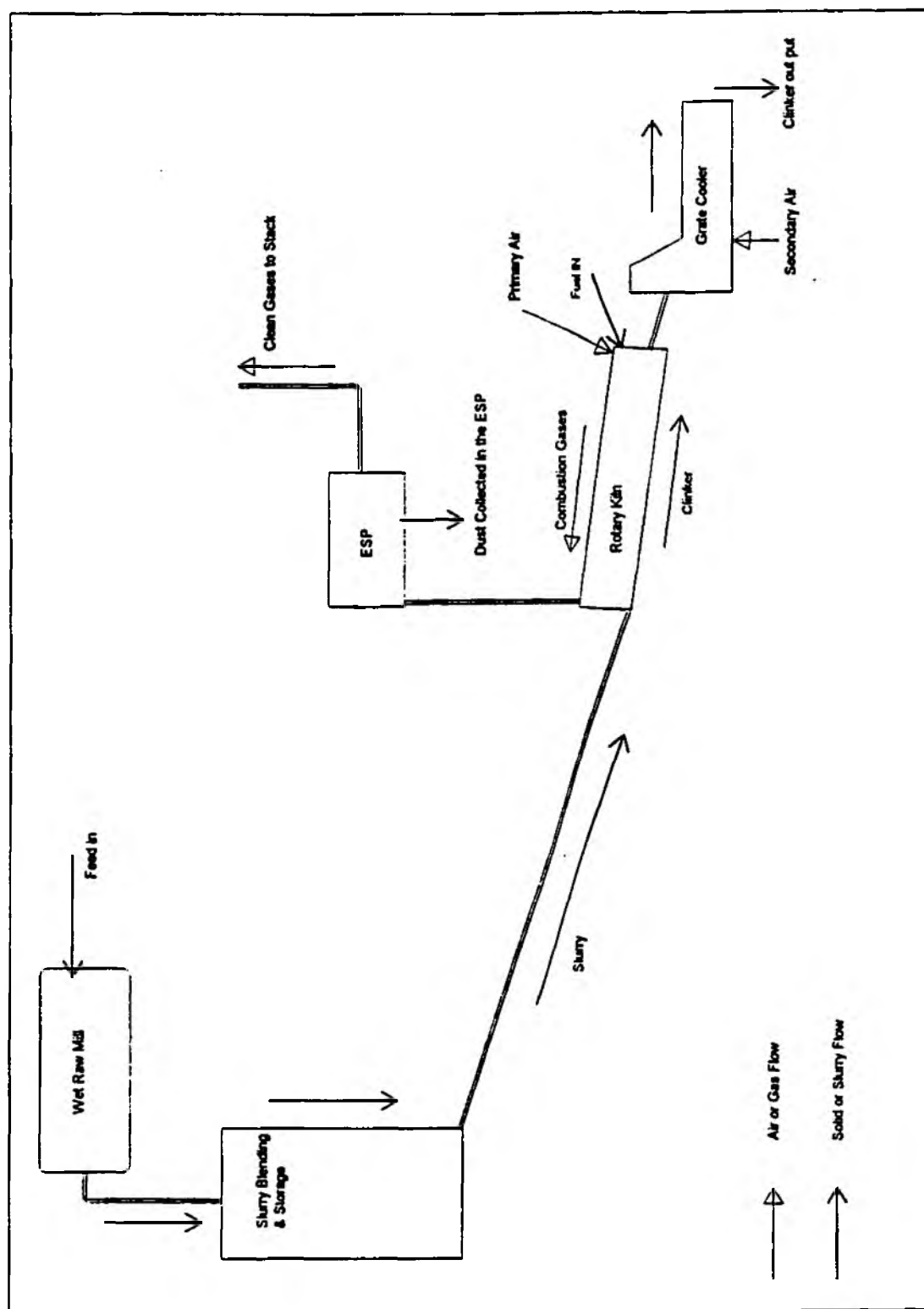


FIGURE 2.2 : SEMI-WET KILN : SCHEMATIC DIAGRAM OF PROCESS

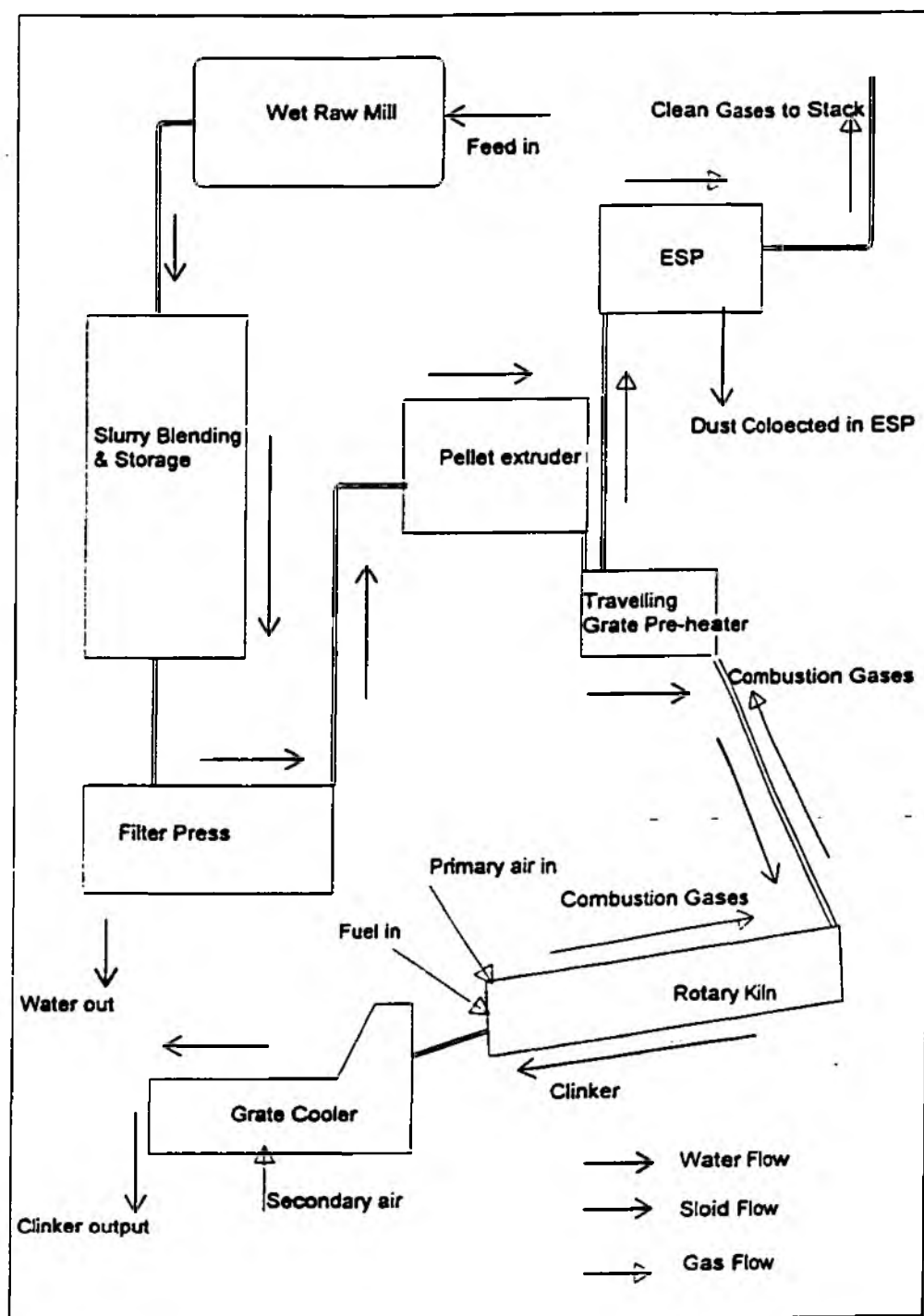


FIGURE 2.3 : SEMI-DRY KILN : SCHEMATIC DIAGRAM OF PROCESS

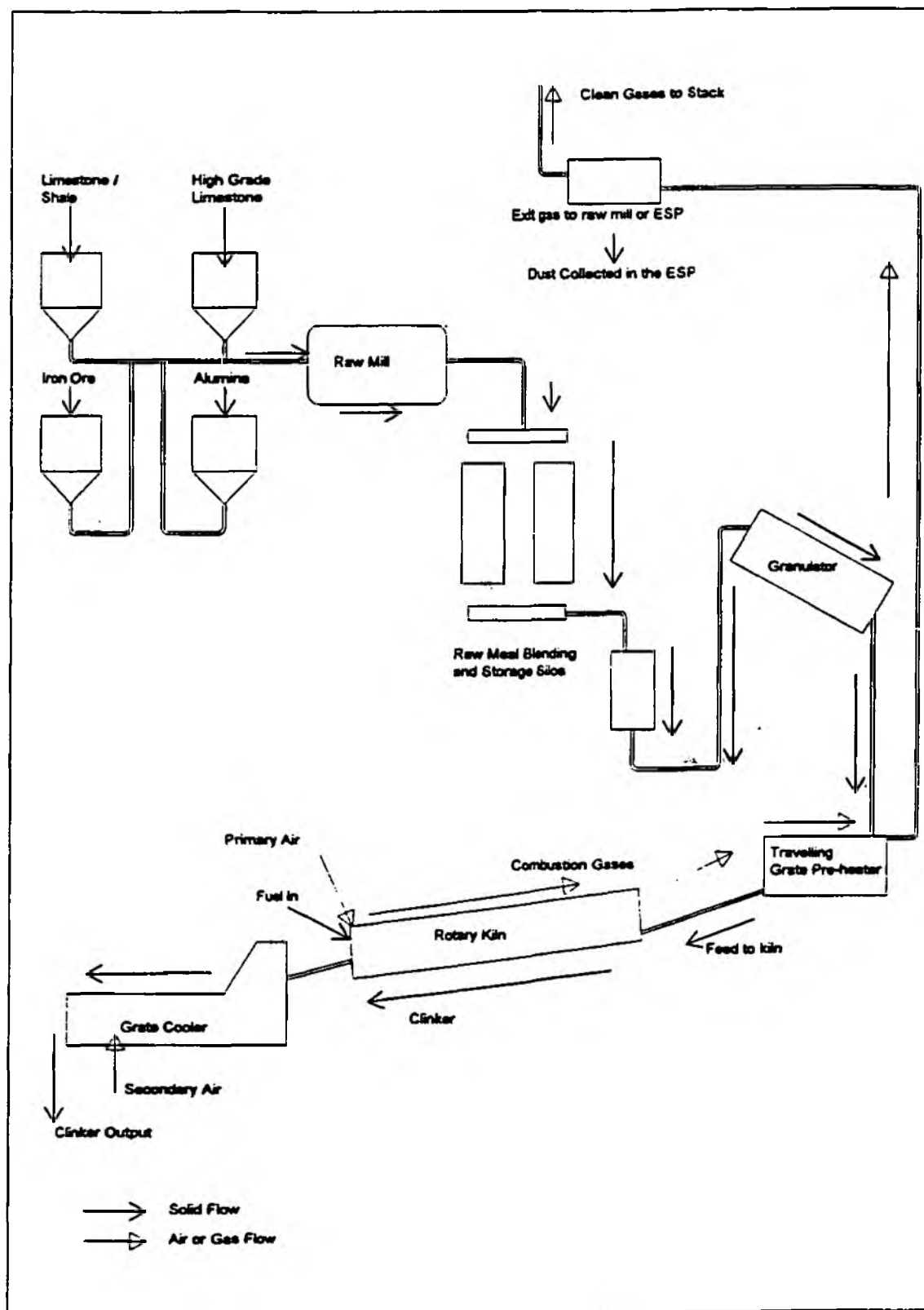
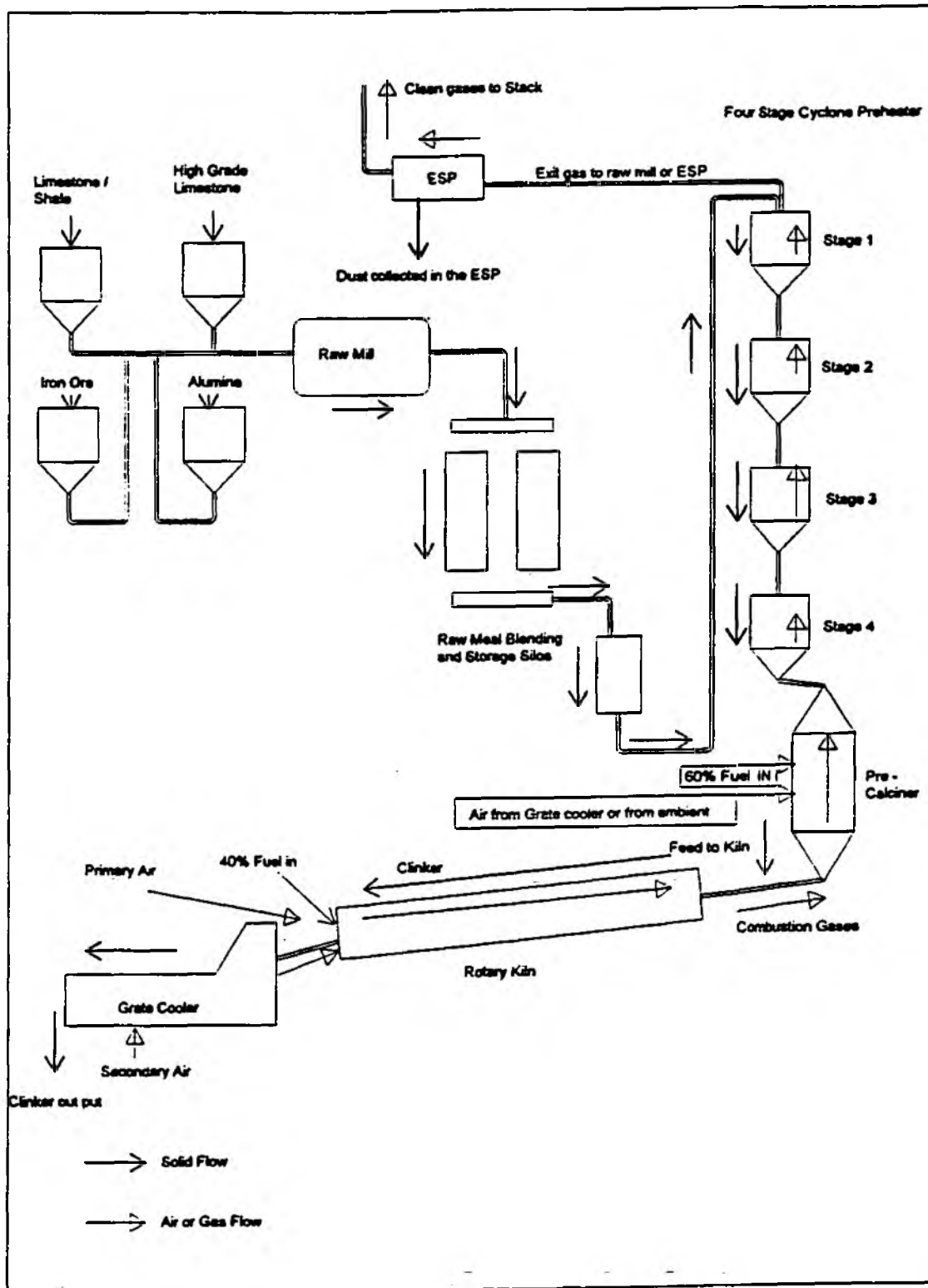




FIGURE 2.4 : DRY KILN : SCHEMATIC DIAGRAM OF PROCESS



In all cases the feed enters the system and moves down through a slightly inclined and slowly rotating kiln against a counter current of hot gases produced by the burning of the fuel in the burning zone of the kiln. After entering at the cooler end of the kiln and having undergone calcination, the feed materials react in the burning zone to form clinker. The hot clinker is then cooled by heat exchange with the combustion air. Further cooling is achieved by additional clinker coolers.

### **Clinker Grinding (cement milling)**

The clinker is stored in covered halls or silos before undergoing the final stage of the manufacturing process; this is the grinding of the clinker mixed with 3-8% gypsum and other additives as required to form the final cement product. The purpose of the grinding is to create a large surface area for reaction when the water is added and the purpose of the gypsum is to prevent instant setting of the cement.

The cement has to be ground fine enough to meet the requirements for strength properties specified in current standards or for particular customer requirements. The grindability of cement is complex and not fully understood. The specific power consumption required to obtain a certain fineness varies from 25% below to 50% above the average. Factors that can have an influence include: lime saturation, high content of very small pores, crystal size, cooling velocity after burning, and age of clinker after burning.

Various surface active agents are used as grinding aids by counteracting agglomeration of very fine particles; the following are commonly used: triethanolamine (TEA), triethanolamineacetate, ethylenglycol, propylenglycol, Hea-2, and DDA-7. With these agents open circuit grinding to finer levels is possible and for closed circuit grinding, the output may be increased so that the costs of the grinding aids are more than fully compensated.

The grinding process accounts for about 40% of the total electricity consumption of the plant.

The competing processes are outlined below.

#### **2.1.2.1 The Wet Process**

The moisture content of a typical slurry is 30-40%. For a large kiln with a daily output of 2000 te, between about 1300 and 2100 te of water per day must be driven off. This results in a much higher fuel consumption than the other processes per tonne of clinker produced. This cost penalty is the principal disadvantage of the wet process and accounts for its decline in recent years; however the high moisture content of the raw materials in the UK means that the wet process has been used extensively.

In comparison with kilns of similar output for the other process types, wet kilns are longer and have a larger diameter in order to accommodate the greater volumes of gases involved. The size effect can be reduced slightly by reducing the diameter down the length of the kiln. The large volume requires a high induced draught fan capacity. The large size of these kilns makes them more difficult to supply and maintain than kilns for other processes of similar capacity. Systems of chains are suspended across the kiln to facilitate heat exchange with the hot gases by tumbling the feed material.

Wet preparation does have some advantages over dry milling. These include :

- i) achieving a homogeneous blend is easier;
- ii) a slurry is easier to transport around the process by pumping;
- iii) a slurry results in lower dust losses from the system and hence lower particulate emissions.

#### *2.1.2.2 The Semi-wet Process*

The slurry preparation is the same for this process as for the wet process; however, before the slurry is fed to the kiln much of the water is removed. Various methods are used to remove water from the slurry; these include: pressure filtration, rotary drum dryers, and dryer crushers.

This partial water removal results in some cost savings over the wet process as it is cheaper to remove the water mechanically than by using fuel to burn it off in the kiln. The size of kiln required for a given capacity is also smaller since the volume of the feed is reduced.

A filter press typically reduces the moisture content to 17-21% producing a moist cake. Production of the cake is on a batch basis and it is stored in silos. Before being fed to the kiln the material may be made into pellets by passing through an extrusion press. These are then put on a moving grate preheater to be dried and partly calcined by the hot exhaust gases from the kiln before entering the kiln.

As an alternative preparation, the moist cake can be fed from the silo to a hammer crusher where drying is also effected by the kiln exhaust gases. Sometimes the cake is fed directly to a kiln fitted with chains as in the wet process; however this is less fuel efficient than the two previous methods.

The semi-wet process retains the wet process's environmentally beneficial property of low dust emissions.

#### *2.1.2.3 The Semi-dry Process*

The semi-dry process is still used but is being replaced by the dry process (described in the next section). This process is used when the material has a low average moisture content (<12%) .

The raw material is prepared in the same way as in the dry process but is then "nodulized" using as little water as possible to form nodules of uniform size - about 12 mm across for optimum permeability. The nodules are then fed directly to a moving grate, double-pass preheater in a similar fashion to that in the semi-wet process.

The thermal efficiency of this process is similar to that of the dry process; however the preheater exhaust gases cannot be used for raw material milling or drying.

#### *2.1.2.4 The Dry Process*

This process uses the same basic primary raw materials as the wet process but with the moisture content of the limestone and shale generally being between 2% and 15%. The material is crushed at the quarry or at the cement plant. The crushed material is stockpiled and although the storage is covered there is the potential for fugitive dust releases that does not exist for the wet processes.

The raw materials are then mixed in their calculated proportions and sent to the raw mill where they are ground to a fineness of typically 10% retention on a 90 micron sieve. The following types of mill are used: air swept ball, closed circuit tube, double rotator, and roller. The roller mill is the preferred choice if the materials are not very abrasive as this is the most energy efficient method.

The ground material is then dried in the raw mill using the hot exhaust gases from the preheater or the kiln. If the raw materials have a high moisture content then additional modes of drying can be employed; these include: a separate hot gas generator feeding to the mill inlet; or - placed before the raw mills - a rotary dryer, or a dryer crusher; or using exhaust air from the clinker cooler.

The mill product is then pneumatically fluidized, mixed and then transferred to storage silos. A sufficient buffer of material - at least three days worth is usual - is maintained to allow operation of the kiln during maintenance and repair periods of the milling system. Again there is the potential for fugitive dust emissions from the storage of dry material.

The raw meal is transported from the silos to the top of the preheater tower by a series of conveyor systems - both mechanical and pneumatic.

Modern kilns have three components - the preheater, the pre-calciner and the kiln itself. These are much smaller and have a higher throughput of material per unit volume than the older long dry kilns in which final drying, heating, calcination, and clinkerization all take place in the kiln.

The purpose of the preheater is to raise the temperature of the raw meal rapidly; this is achieved by entraining hot gases with the finely divided raw meal. A four stage cyclone preheater can heat the raw meal up to 800°C in 25 seconds.

The hot raw meal then enters the pre-calciner. Most of the calcination takes place in this stage and up to 60% of the total fuel requirement is expended. The environmental advantage of this method over the pre-heater kiln without calciner is that less NO<sub>x</sub> is produced; this is because 60% of the fuel is burnt in a relatively low temperature flame of the pre-calciner compared with flame temperatures of 2000°C in the kiln. Finally the material enters the kiln where calcination is completed; sintering into cement clinker occurs in the burning zone.

Transportation of the dry material between the various stages in the process requires more energy than the simple pumping required for the wet process and there are more opportunities for fugitive dust emissions.

## **2.2 Impacts on the Environment - Qualitative Discussion**

The environmental impacts of cement manufacturing processes are essentially very similar to those from lime manufacturing processes. This section summarises the key impacts pertinent to cement processes and prioritises them in a general sense so that future effort and resources can be better directed at the most important environmental issues. Clearly, though, the need to reduce releases at individual sites will depend on the local impacts and local priorities.

In the analysis of both cement and lime processes, the environmental impacts have been considered in terms of three domains:

- near field :           less than 5 miles
- far field:             5 - 50 miles
- global:                over 50 miles

The types of pollutant emitted to the above fields are shown in Table 2.3.

**TABLE 2.3 : SUMMARY OF ENVIRONMENTAL IMPACTS AND POLLUTANTS IN EACH DOMAIN**

Near Field	Far Field	Global
noise visual particulate liquid waste solid waste gases	visual particulate gases	gases

Appendix A.1 provides a detailed qualitative review of these generic impacts for both cement and lime processes in each domain, and Appendix A.2 assesses their significance in terms of air quality, water resources, human health, flora and fauna, land-use and the economy. Appendices

A.3, A.4 and A.5 then summarise, and prioritise the generic impacts in terms of whether they are potential or actual, and how easily each impact can be controlled, for each domain respectively.

The principal conclusions from this analysis are summarised below. The most significant impacts from current manufacturing processes are:

- Local air quality from fugitive releases of particulates. For most industrial processes reduction of global and far field emissions may represent a reasonable environmental approach; however for the cement industry, the large quantities of dust (a proportion of which is alkaline, and has a detrimental effect on local flora and fauna) emitted relative to other pollutants mean that the near field effects tend to dominate those occurring further afield. In spite of this, the approaches adopted for the cement industry hitherto have followed those of other industries and have concentrated on reducing global and far field emissions. Consequently the time, effort, and resources expended have run the risk of being disproportionately high compared to the actual environmental benefits gained. That is not to say that all emphasis should now be placed on near field emissions ignoring far field and global emissions completely - these can still be important for some sites.
- Far field air quality from stack releases of SO<sub>2</sub> and NO<sub>x</sub> contributing to the total national emissions of acid gases.
- Land-use from mining activities, (and subsequent landfill disposal of wastes in the quarry associated with cement production).

Impacts of a lesser significance, but which should still be considered are:

- Water pollution from site run-off; the alkaline nature of the effluent could potentially cause an adverse effect on water courses if released directly.
- Global pollution from CO<sub>2</sub> releases. CO<sub>2</sub> is released from the combustion of fuels and in the clinkerisation of the raw meal. Other than improving the total energy efficiency of the process, including the CO<sub>2</sub> benefit from burning wastes, no practical techniques are available for reducing CO<sub>2</sub> emissions.

### **2.3 Achievement of Current Standards**

The HMIP's Chief Inspector's Guidance to Inspectors for cement manufacture (HMIP, 1992) gives limits for releases into air for new plant and existing plant. These are shown in Table 2.4.

The following are prescribed substances for release into air:

particulate matter,

oxides of sulphur and other sulphur compounds,  
 oxides of nitrogen,  
 oxides of carbon.

For releases into water there are no prescribed substances and for releases into land the prescribed substances are alkaline earth metal oxides.

**TABLE 2.4 : LIMITS SPECIFIED BY HMIP FOR RELEASE TO AIR FROM CEMENT MANUFACTURE**

Specified Substance		Limit (mg/m <sup>3</sup> )
particulate matter	kilns <sup>(a)</sup>	50
	clinker coolers	100
	milling and grinding	50
	all other contained sources	50
oxides of sulphur <sup>(b)</sup> (expressed as SO <sub>2</sub> )		750
oxides of nitrogen (expressed as NO <sub>2</sub> )	wet process	1800
	semi-dry/semi-wet process	1500
	dry process	1200

- (a) for existing kilns this standard should be achieved by 1 April 1998 unless they are modified in order to increase output or have their arrestment equipment totally replaced in which case the limit will have immediate effect
- (b) a higher release limit may be considered in cases where the applicant can demonstrate to the satisfaction of HMIP that, owing to the sulphur content of the raw materials (excluding fuel), it would entail excessive cost to achieve the limit specified

### 2.3.1 Actual Releases

This section reviews releases to air, water, and land.

#### 2.3.1.1 Releases to Air

The emission data in the following discussion are taken from the 1982 PCA survey (Waterhouse, 1983) of kiln emissions.

## Nitrogen Oxides

Table 2.5 shows typical NO<sub>x</sub> emissions from US cement processes from a wet kiln and two types of dry kiln. The figures for specific emission show little difference between wet and dry kilns and the figures for concentration suggest that wet kilns have lower NO<sub>x</sub> emissions than dry kilns. These data are from 1983 for US plant. The results of UK NO<sub>x</sub> monitoring however showed much greater differences between the specific emissions of wet and dry kilns with the dry kilns having the lower emissions. The results of some UK NO<sub>x</sub> monitoring are summarized in Table 2.6; the information was obtained from the BPEO assessment of burning CEMFUEL® at the Ribblesdale Works (AEA Technology, 1994) and Ketton Works (AEA Technology, 1995), an assessment of the use of SLF (Secondary Liquid Fuel) secondary at the Barrington Works (ERM, 1995), and quarterly returns to HMIP Thornaby from Blue Circle Cement (BCC, 1995), Weardale Works. Table 2.6 shows that the NO<sub>x</sub> releases from UK cement kilns are generally well below the limits in IPR 3/1 for all types of kiln.

**TABLE 2.5 : TYPICAL NO<sub>x</sub> EMISSIONS FROM DIFFERENT KILN TYPES**

Kiln Type	Specific Emission (mg/kg(clinker))	NTP Concentration (mg/m <sup>3</sup> )
wet	2500	670
long dry	2900	1600
dry with preheater, pre-calciner	1900	1000

Source : Waterhouse 1983

## Sulphur Dioxide

Table 2.7 shows typical SO<sub>2</sub> emissions from a wet kiln and two types of dry kiln. This table demonstrates how the difference between kiln types depends upon how the emissions are expressed. The wet kilns have twice the specific emissions of the long dry kilns, but because they have about twice the specific volume of exhaust gases, the stack concentrations are about the same. The effectiveness of the preheater or pre-calciner in reducing SO<sub>2</sub> emissions is clearly demonstrated in both respects.

As Table 2.7 shows, average US releases of SO<sub>2</sub> from wet kilns and long dry kilns in 1983 were well above the IPR 3/1 limit of 750 mg/m<sup>3</sup>, whereas those from dry kilns achieve releases just below the limit.



**TABLE 2.6 : NO<sub>x</sub> LEVELS IN UK KILN EMISSIONS**

Works	Kiln	Type	Ref.	Specific Emission mg/kg(clinker)	NTP Concentration mg/m <sup>3</sup>
Ribblesdale	5	wet	(6)	3340	930
Barrington	4	wet	(8)	3590	970
Weardale	1	semi-dry	(9)	1650	610
Weardale	2	semi-dry	(9)	1890	700
Ketton	7	long dry	(7)	1480	820
Ribblesdale	7	precalc.	(6)	830	460

Source: UK Monitoring Data, various sources

**TABLE 2.7 : TYPICAL SO<sub>2</sub> EMISSIONS FROM DIFFERENT KILN TYPES**

Kiln Type	Specific Emission (mg/kg(clinker))	NTP Concentration (mg/m <sup>3</sup> )
wet	8000	2100
long dry	4000	2100
dry with preheater, pre-calciner	1100	600

Source: Waterhouse 1983

### Particulates

An assessment of particulate emissions is complicated by the fact that the kiln is not the only source of particulate material. Other sources include: the milling of the raw material, the coal and the clinker, the clinker coolers and transfer points along the materials transport routes. How these other sources are dealt with will depend on the detailed design of the plant. The following discussion concentrates on emissions from the kiln stack, but other possible sources should not be overlooked. If abatement of stack emissions reduces particulate concentrations to lower levels, other sources may become the dominant contributors to total emissions.

The averaged results of stack monitoring for six kilns are given in Table 2.8. The conversion from quoted concentrations to specific emissions is done on the same basis as for SO<sub>2</sub> and NO<sub>x</sub>. Where results are also quoted for the partial burning of recycled liquid fuels, the figure quoted here is for the case with 100% coal burning.

**TABLE 2.8 : PARTICULATE LEVELS IN UK KILN EMISSIONS**

Works	Kiln	t/ye	Ref	Specific Emissions mg/kg(clinker)	NTP Concentration mg/m <sup>3</sup>
Ribblesdale	5	wet	(6)	178	48
Barrington	4	wet	(8)	270	73
Weardale	1	semi-dry	(9)	41	15
Weardale	2	semi-dry	(9)	54	20
Ketton	7	long dry	(7)	83	46
Ribblesdale	7	precalc.	(6)	34	19

Source: UK Monitoring Data, various sources.

These emissions are already abated with electrostatic precipitators. The numbers quoted are averages of "noisy" signals, so not too much significance should be read into the differences between kilns and kiln types. Instead the table should be seen as showing the range of typical values of particle concentration currently being achieved in the UK.

These data show that average releases range from 20 mg/m<sup>3</sup>, to over 70 mg/m<sup>3</sup> resulting in some kilns exceeding the IPR 3/1 limit of 50 mg/m<sup>3</sup>.

### Heavy Metals

Cement kiln emissions are also monitored for heavy metal levels. On the whole the reported values are close to, or below, the limits of detection, and so the signal is noisy. Rather than give results for all the metals, this report concentrates on lead because measured levels for this metal are generally significantly higher than the level of detection. Lead is also the one metal of those known to be emitted for which an Environmental Quality Standard is currently given. Values of measured emission concentrations are shown in Table 2.9. There are, however, currently no emission limits for cement kilns for lead.

**TABLE 2.9 : LEAD LEVELS IN UK KILN EMISSIONS**

Works	Kiln	Type	Ref.	Specific Emission (ng(TEQ)/kg(cl))	NTP Concentration (ng(TEQ)/m <sup>3</sup> )
Ribblesdale	5	wet	(6)	0.78	0.21
Barrington	4	wet	(8)	0.24	0.064
Weardale	1	semi-dry	(9)	not given	not given
Weardale	2	semi-dry	(9)	not given	not given
Ketton	7	long dry	(7)	0.09	0.052
Ribblesdale	7	precalc.	(6)	0.03	0.016

Source : UK Monitoring Data, various sources.

### Dioxins

More recently cement kiln emissions have been monitored for dioxin emissions. In what follows the word "dioxin" is used to cover all those polychlorinated dibenzo dioxins and furans to which a TEF (Total Equivalence Factor) has been assigned. Measured TEQ emission concentrations and the corresponding specific emissions are shown in Table 2.10.

**TABLE 2.10 : DIOXIN LEVELS IN UK KILN EMISSIONS**

Works	Kiln	Type	Ref.	Specific Emission (TEQ) (ng/kg clinker)	NTP Concentration (TEQ) (ng/m <sup>3</sup> )
Ribblesdale	5	wet	(6)	0.96	0.26
Barrington	4	wet	(8)	0.52	0.14
Weardale	1	semi-dry	(9)	not given	not given
Weardale	2	semi-dry	(9)	not given	not given
Ketton	7	long dry	(7)	0.01	0.006
Ribblesdale	7	precalc.	(6)	0.16	0.09

Source : UK Monitoring Data, various sources.

#### **2.3.1.2 Releases to Water**

A cement plant does not generate significant quantities of liquid effluent. Liquid effluent that does arise does so from site surface water run-off from rain and deliberate washing down of surfaces. It is therefore possible that such water may be contaminated with particulate matter and oil. Where there is any oil contamination water should be treated with an efficient oil/water separation/interceptor system before discharge to a watercourse. In some cases further treatment may be required to remove dissolved pollutants.

#### **2.3.1.3 Releases to Land**

Cement kiln dust (CKD) is the principal release. CKD in the first instance should be recycled. CKD which cannot be re-used is sent for landfill where it is monitored and the alkaline leachate treated with hydrochloric acid. Without strict control, leachate from CKD in landfills has the potential to cause significant environmental problems.

### **2.4 Review of Available Techniques**

The techniques currently in use in the following countries have been assessed: UK, USA, and most European countries.

The following two sections examine "general" and "specific" techniques, for controlling releases to air respectively. "General techniques" refer to improvements to the cement manufacturing process which can affect a range of pollutants. The key techniques are: kiln type, kiln running and fuel selection. "Specific techniques" are those which are designed to reduce particular pollutants, such as particulates, SO<sub>2</sub> and NO<sub>x</sub>, and include such measures as gas filtration, specific process configurations and gas scrubbing systems. All techniques reviewed are either in use in the UK or have been used elsewhere in the world and are potentially applicable to the UK industry. Tables 2.11 and 2.12 summarise the general and specific techniques respectively. Each technique is profiled in more detail along with the associated costs in Appendices B4, B.5 and B.6.

#### **2.4.1 General Techniques**

##### **2.4.1.1 Type of Kiln**

All the following discussions are made relative to the state of affairs for a dry kiln with a pre-calciner. The key issues with respect to the environmental performance of semi-wet dry and dry kilns are:

#### Wet Kiln

- More fuel is required to burn-off the greater quantities of water ; this results in greater CO<sub>2</sub> and NO<sub>x</sub> emissions.
- The absence of a pre-calcliner means the fuel is burnt at a high temperature which results in greater NO<sub>x</sub> emissions.
- The dust emissions are much less as wet rather than dry material is handled and transported around.
- Less electrical energy is required to move wet material around.
- There is a greater use of water resources.
- The sulphur content in the fuel may have an influence on the total SO<sub>2</sub> emissions because there is no pre-calcliner to scrub the SO<sub>2</sub>.

#### Semi-wet

- There is not quite so much water to burn off as for the wet process as some of the water is removed mechanically. The fuel consumption and consequent CO<sub>2</sub>, NO<sub>x</sub> emissions are therefore less than for the wet process but still greater than for the dry process.
- Slightly more electrical energy is required than for the wet process to perform the filter pressing.

TABLE 2.11 : SUMMARY OF GENERAL EMISSION CONTROL TECHNIQUES FOR THE CEMENT INDUSTRY

Technique		Pollutant	Advantage	Disadvantage
kiln type	wet	particulate	lower emissions than other kiln types	
		SO <sub>2</sub> , NO <sub>x</sub> , CO <sub>2</sub>		higher emissions due to higher fuel consumption per tonne of clinker produced - SO <sub>2</sub> from fuel could be significant fraction of total SO <sub>2</sub> released
	semi-wet	particulate	as above	
		SO <sub>2</sub> , NO <sub>x</sub> , CO <sub>2</sub>		as above but less fuel used than in wet process
	semi-dry	particulate		higher emissions
		SO <sub>2</sub> , NO <sub>x</sub> , CO <sub>2</sub>	lower emissions than wet process	
	dry	particulate		higher emissions
		SO <sub>2</sub> , NO <sub>x</sub> , CO <sub>2</sub>	overall less fuel usage therefore lower emissions (majority of SO <sub>2</sub> trapped in calciner)	
kiln control		SO <sub>2</sub> , NO <sub>x</sub> , CO <sub>2</sub>	improved plant efficiency leads to lower emissions	potential for CO trip in ESP
fine grinding of fuel		NO <sub>x</sub>	lower emissions due to lower flame temperature	
fuel selection	gas	SO <sub>2</sub> , NO <sub>x</sub> , CO <sub>2</sub>	low CO <sub>2</sub> production, SO <sub>2</sub> reduction depends on type of kiln (some possible for wet), easy combustion control	higher fuel usage, high NO <sub>x</sub> production, high cost
	oil	SO <sub>2</sub> , NO <sub>x</sub> , CO <sub>2</sub>	easy combustion control, lower NO <sub>x</sub> emissions than for gas due to lower temperature	higher CO <sub>2</sub> than for gas
	coal	SO <sub>2</sub> , NO <sub>x</sub> , CO <sub>2</sub>	as for oil, chlorine present in fuel can help to reduce alkalinity of kiln dust	higher NO <sub>x</sub> emissions if not milled finely, extra energy and local particulate emissions from fuel preparation and handling, high sulphur content can contribute to total SO <sub>2</sub> production for wet kilns
	pet coke	SO <sub>2</sub> , NO <sub>x</sub> , CO <sub>2</sub>	as for coal	as for coal
	SLF	SO <sub>2</sub> , NO <sub>x</sub> , CO <sub>2</sub>	lower NO <sub>x</sub> from stack (demonstrated by trial runs for certain fuel mixtures - new combinations will need their NO <sub>x</sub> reductions similarly demonstrated)	public concern over perceived health hazard

TABLE 2.12 : SUMMARY OF SPECIFIC ABATEMENT TECHNIQUES FOR THE CEMENT INDUSTRY

Abatement technique	Pollutant	Applicability
ESP ~15-20 mm WGap	particulate	best option for particulate abatement
cyclone separators		not suitable as final separators
cyclone gravel bed		inherent weakness for cement or lime
bag filters 150-200 mm WGap		applicable but not as suitable as ESPs
Materials control measures: eg, coverage dust hoods, clinker/feed storage		suitable for all works
FGD wet scrubber	SO <sub>2</sub>	not the most suitable due to high costs
FGD dry scrubber		some processes can be adapted
vortex scrubber		not suitable
selective quarrying		applicable to some works
import low S fuel		depends on economic factors
low NO <sub>x</sub> burner	NO <sub>x</sub>	applicable to all kilns
NO <sub>x</sub> scrubber NH <sub>3</sub> injection		can be expensive, but technically possible
SCR (selective catalytic reduction)		Expensive and needs to be designed for site
activated charcoal filter		not ideally suited, expensive, and also a potential fire and explosion hazard
POLVITEC process - integral process for SO <sub>2</sub> as well		not suitable for UK industry
Secondary Liquid Fuels (SLF)		possible technique for NO <sub>x</sub> reduction

- Less water is wasted than in the wet process.
- The same arguments made for the wet process about higher NO<sub>x</sub> and SO<sub>2</sub> emissions as a result of not having a pre-calciner also apply to the semi-wet process.
- The dust emissions are also much less than for the dry process.

#### Semi-dry

- Similar arguments apply to this process as do to the semi-wet process with the possible exception that dust emissions might be slightly greater than for the semi-wet process.

#### Dry

- A pre-calciner allows some fuel to burn at a lower temperature reducing NO<sub>x</sub> emissions. For dry kilns without a pre-calciner this effect is reduced. However reduced NO<sub>x</sub> emissions as a result of the lower fuel requirement to burn the water off applies to all dry kilns.
- The pre-calciner also scrubs SO<sub>2</sub> resulting in lower emissions.
- More electrical energy is required to move the dry material around than in the wetter processes.
- The dust emissions are greater than for the wetter processes.
- There is a negligible use of water resources.

#### 2.4.1.2 Improved Kiln Running

One option to explore is whether reductions in emissions can be achieved through better control of the existing equipment. Now that a considerable body of monitoring data has been built up on emissions from cement kilns, it is clear that there are variations of a factor of 2 to 4 in SO<sub>2</sub> and NO<sub>x</sub> emissions over time scales of weeks and months. Work is currently under way within the cement industry to understand the causes of these variations. If these are found to be amenable to control, and kilns can be run consistently at the lower emission level, then considerable reduction in emission could be achieved without the need for investment in new plant.

The question of SO<sub>2</sub> control in cement kilns depends strongly on the process used. Pre-heaters and pre-calciners act as effective desulphurization devices for SO<sub>2</sub> released from fuel combustion in the kiln, and the emissions are caused mainly by release from the raw materials as they heat up. The (higher) SO<sub>2</sub> releases from wet process kilns are due to release from raw material within the kiln and in part from the fuel. The release of sulphur as SO<sub>2</sub> in the burning zone is strongly dependent on the



oxygen level (BCA, 1996). Under more oxidising conditions the sulphur is stabilised as sulphate, which is retained in the clinker. This dependence has been shown by plotting  $\text{SO}_2$  concentrations in the bypass gas against the percentage of oxygen at the kiln exit. Above 2% oxygen, the  $\text{SO}_2$  concentration is virtually zero. Below this level it begins to rise slowly, reaching 100 ppm at around 1% oxygen. At still lower oxygen levels, the  $\text{SO}_2$  concentration rises very rapidly, reaching up to 800 to 1200 ppm at around 0.5% oxygen. This rapid change in emissions for a small change in kiln conditions may be one explanation for the observed fluctuations in emissions.

$\text{NO}_x$  production depends almost entirely on combustion conditions, and therefore might be especially amenable to reduction by process control. Unfortunately low  $\text{NO}_x$  emissions require reducing conditions, which is the opposite requirement for  $\text{SO}_2$  control and does not allow production of satisfactory quality clinker. A comparison between preheater oxygen levels and  $\text{NO}_x$  concentrations shows a linear rise from around 100 ppm NO in the preheater at 1% oxygen to around 300 ppm NO at 5% oxygen (BCA, 1994). From the point of view of minimising both emissions, an oxygen level of around 1.5% in the kiln would appear to be indicated.

Automatic kiln control systems, based upon fuzzy logic, such as F.L. Smidth's Fuzzy II and Blue Circle's Linkman although primarily intended to maximise production, maintain product quality and minimise fuel consumption are also able to control  $\text{NO}_x$  emissions. The Fuzzy II system uses a combination of a short term and a long term strategy. If the  $\text{NO}_x$  emission is found to be too high, the short term strategy reduces the level of excess oxygen, which reduces  $\text{NO}_x$  levels immediately. The long term strategy then cools the kiln to ensure that the levels remain low.  $\text{NO}_x$  reductions of around 25% are claimed for these control systems. For kilns without pre-heaters or pre-calciners it may be worth investigating what effect these controls have on  $\text{SO}_2$  emissions as well.

#### 2.4.1.3 Fuel Selection

The choice of fuel used in the current manufacturing process can have an important effect on releases to air. The main fuels used in the UK are coal (75 - 90%), petroleum - coke (pet-coke) (10 - 25%), and a range of waste-derived fuels, including Secondary Liquid Fuels (SLF).

In many countries it has been the practice to burn waste-derived fuels in cement kilns and a list of alternative fuels is given in Table 2.2. In the past three years the practice of SLF use in cement kilns has been taken up in the UK. The primary motivation for doing this is fuel economy (though some countries specifically look to cement kilns to play a part in their waste management strategy). In addition, however, a body of evidence has now been built up to indicate that the burning of SLF reduces emissions of  $\text{SO}_2$  and  $\text{NO}_x$ . Where SLF is used, regulations (94/67/EC) governing the incineration of hazardous waste must be applied. This piece of legislation imposes tighter standards on releases of particulates, relative to IPRC 3/1.

Since SLF contains significantly less sulphur than the coal or petroleum coke it replaces, one might expect that in wet and long dry kilns, the burning of SLF would reduce  $\text{SO}_2$  emissions. Such a

reduction was reported in the Barrington BPEO study. Substituting 25% of the coal with SLF was accompanied by a reduction in SO<sub>2</sub> concentration from 1860 mg/m<sup>3</sup> to 1030 mg/m<sup>3</sup>. A similar effect was not seen in kiln 5 at Ribblesdale. This is not so surprising, given that the raw material is a larger source of sulphur than the fuel. Even if the fuel were the only source of sulphur, a reduction in the sulphur input could not account for the size of the effect seen in Barrington. It may be that the introduction of SLF improved the control of the flame and hence the retention of sulphate in the clinker.

The effect of SLF burning on NO<sub>x</sub> emissions is more clear cut. Reductions might be expected, for two reasons. Burning liquid fuels gives better flame control while blockages in solid fuel feed can cause the flame to become temporarily oxygen rich, giving enhanced NO<sub>x</sub> production. Liquid fuels also cause the flame to become longer and "lazier", which is correlated with lower NO<sub>x</sub> levels. Results from BPEO studies, presented in Table 2.13, bear out these expectations.

**TABLE 2.13 : SLF BURNING AND NO<sub>x</sub> LEVELS**

Kiln	NTP NO <sub>x</sub> conc. mg/m <sup>3</sup> coal only	NTP NO <sub>x</sub> conc. mg/m <sup>3</sup> with SLF	% SLF	% NO <sub>x</sub> reduction
Ribblesdale 5	927	519	50%	44%
Barrington 4	968	724	25%	25%
Ketton 7	605	550	10%	9%
Ribblesdale 7	457	414	25%	9%
Ketton 8	916	617	10%	33%

*Source : UK Monitoring Data*

This is strong evidence of a correlation between SLF burning and NO<sub>x</sub> reduction. Indeed the first three points show an almost linear relation. The last two points are of lower significance because they are based on a single pair of measurements only. The first point, that for kiln 5 at Ribblesdale, which shows the largest effect, is particularly robust because it is based on four pairs of measurements over a period of 18 months. This evidence suggests strongly that an effective way of obtaining substantial reductions in NO<sub>x</sub> emissions is to burn larger amounts of SLF.

#### 2.4.2 Specific Techniques

The specific techniques in this section are reviewed in relation to the three key pollutants requiring abatement, as follows:

Particulates	• ESPs
	• Cyclone separators
	• Cyclone gravel levels
	• Failure/bug filters
	• Materials handling measures
SO <sub>2</sub>	• Selective quarrying
	• Abatement
NO <sub>x</sub>	• Combustion Technology
	• SNCR/SCR (Selective Non Catalytic Reduction/Selective Catalytic Reduction)
Combined Pollutants	• Carbon filtration.

Technical and cost details of these techniques are profiled in Appendices B.4, B.5, and B.6.

#### 2.4.2.1 Particulate Control

##### **Electrostatic Precipitations (ESP)**

In this device the electrically-charged dust particles are collected and removed from the gas by an electrode. Designs in which the gas with suspended particulate flows between vertical parallel plate electrodes are the most suitable for the large gas volumes from a cement kiln. The dust is removed from the plates by mechanical shaking or rapping and collected either in storage hoppers or by a continuous disposal system.

The collection efficiency of an ESP is not as restricted by fine particle sizes as cyclones or wet scrubbers. A problem with ESPs, however, is that if carbon monoxide levels become too high in the ESP there is a risk of explosion. CO trip devices are therefore fitted which activate at a CO level of typically 0.5% CO by volume. This results in very high dust emissions to the atmosphere during the short period in which the precipitator is de-energized.

Long kilns with no preheater system are particularly susceptible to CO trips especially at start-up or when the rate or composition of the fuel changes.

##### **Cyclone Separators**

These devices rely on centrifugal force to separate the particles from the gases. The two important parameters are the size of the particle and the mass of the particle. The theoretical cut-off line for the separation is 10 µm. In practice it is difficult to separate particles less than 20 µm. Cyclone separators are sensitive to the entry velocity and the performance deteriorates significantly should the entry velocity decrease; the pressure drop is proportional to the square of the entry velocity.

These devices are suitable for pre-calciners to trap most of the material for recycling but are not suitable as abatement equipment which needs to be able to trap fine dust.

### ***Cyclone Gravel Bed Filters***

There are two types of gravel bed filters: simple gravel bed and a gravel bed linked to a cyclone. Both are susceptible to preferential flow since both have an extremely large number of parallel flow paths. The gravel moves during its operational life, the paths change and some open up resulting in preferential flow. This feature is an inherent drawback of this system. There are instances of this type of abatement equipment being replaced because of this inefficiency.

### ***Fabric or Bag Filters***

These devices use a filter bag whose woven or needle felt surfaces collect the dust. The collected dust, which is able to absorb  $\text{SO}_2$  as well as entrain fine particulates, forms a cake which is then removed by a pulse or reverse air jet or by shaking the bags mechanically. Typically several bags are arranged in parallel.

Bag filters are very efficient collectors of sub micron fume since the fine material is caught by the fibres of the filter cloth material and by dust already collected on the cloth. The coarse material is trapped within the mesh of the cloth.

For temperatures below  $120^\circ\text{C}$  and for handling small volumes of gas, bag filters usually have a lower capital cost than an equivalent ESP (although the running costs are similar). Bag filters also have the advantage of being able to handle both very small volumes of gas such as that from a conveyor transfer point and larger volumes such as the stack gas.

For higher temperatures, special expensive bags would have to be used. A further disadvantage is that maintenance costs can be high; this is because damaged bags must be replaced promptly as they impair the overall collection efficiency. Also moisture can cause the dust to be sticky which will eventually lead to the filter bags binding; this means the operating temperature should be above the dew point and trace heating may be necessary to avoid condensation on start-up.

### ***Materials Handling Measures***

Dust emissions occur mainly at transfer points and handling areas where dust is created and existing particulates can become airborne. Simple dust hoods with extractor fans and local bag filters are used at these points. Bag filters are suitable for capturing the dust in these applications, as only small quantities of dust and air need to be handled.

In the clinker/feed storage area lack of housing and containment can lead to large quantities of dust becoming airborne. Actual arrangements are site-specific and need to be addressed individually. The basic concept however is to provide good containment.

Fugitive leaks are another source of particulated emissions, and this is particularly relevant to the dry process, although it also applies to the product handling side of all processes. Leaks need to be addressed at each site. Significant improvement can be achieved by good house-keeping, and by regular visual checks on plant equipment.

#### **2.4.2.2 SO<sub>2</sub> Control**

SO<sub>2</sub> releases may be controlled by two principal techniques: selection of raw materials and abatement.

##### ***Selection of Raw Materials (Selective Quarrying)***

The majority of SO<sub>2</sub> emissions are from the sulphur in the feed material. It is claimed that variation can be as much as a factor of 4 to a factor of 10. This approach is to consider a survey of the quarry and where applicable implement a selective quarrying principle to achieve a controlled even emission of SO<sub>2</sub> throughout the lifetime of the quarry. The benefits are a more even stack release, with reduced peaks.

Material selection is facilitated by the large quantities of clinker and feed material which are transported between sites to meet the production demand. Given the large storage facilities for this process it should be relatively easy to implement an approach by which low sulphur feed is imported and blended with material from different quarries.

##### ***Abatement***

SO<sub>2</sub> emissions from large combustion plants can be abated by wet or dry scrubbing of the exhaust gases with calcium carbonate, hydroxide or oxide. The preheater tower of those cement kilns which use one, with its intimate contact between the kiln exhaust gases and large amounts of calcium carbonate and oxide, fits the general description of a flue-gas desulphurisation plant. The problem is that, while the preheater absorbs almost all of the SO<sub>2</sub> from the kiln, further SO<sub>2</sub> is released higher up the tower as the raw material is heated up. These releases do not have the same potential for being scrubbed. When the raw material mill is on and the preheater exhaust gases are passed through it, some reduction in SO<sub>2</sub> is achieved, though the mill is not as efficient as the preheater.

These effects are illustrated by the following data obtained on a dry process kiln with a 4-stage preheater (BCA, 1994). Table 2.14 shows the variation of SO<sub>2</sub> concentration in the gas going up the preheater.

**TABLE 2.14 : SO<sub>2</sub> CONCENTRATION AT EACH PRE-HEATER STAGE**

Location	Temperature (°C)	NTP SO <sub>2</sub> (mg/m <sup>3</sup> )
preheater exit	400	2490
cyclone 1	415	2375
cyclone 2	650	1860
cyclone 3	820	0

Source : BCA, 1994

The fact that there is a point within the preheater where the concentration is zero shows how effective the lower parts of the preheater are in scrubbing the sulphur released in the kiln - including all of the fuel sulphur. However as the raw material heats up it releases more SO<sub>2</sub>, mostly in the 700-800°C temperature range.

Where this comes from is shown by the following analyses of kiln feed sampled from the cyclones presented in Table 2.15.

**TABLE 2.15 : SULPHUR CONTENT OF KILN FEED FROM CYCLONE SAMPLES**

Material	Temperature (°C)	% Sulphur as S <sup>2-</sup>	% Sulphur as SO <sub>3</sub>
kiln feed	80	0.55	0.21
cyclone 1	415	0.49	0.54
cyclone 2	650	0.13	0.86
cyclone 3	820	0.17	1.08
cyclone 4	890	0	1.95
clinker	-	0	2.05

As the raw material is heated up the sulphide content decreases; this is the source of the SO<sub>2</sub> emissions. The increase in sulphate, particularly in cyclone 4, is attributed to coal combustion in the calciner.

If further reductions in SO<sub>2</sub> emissions are required, burnt or hydrated lime, (or calcined raw meal) may be added to the kiln feed at the top of the preheater cyclones, in the downcomer, the conditioning tower, or the raw mill. This has done at Rekingen in Switzerland. Emission levels before abatement were:

400 - 600 mg/m<sup>3</sup> (exhaust gas used to dry material in the raw mill)

800 - 1200 mg/m<sup>3</sup> (raw mill stopped).

By adding 1.5 to 2 kg of calcium hydroxide per tonne of clinker produced to the kiln feed it was possible to comply with the limit of 500 mg/m<sup>3</sup>.

At higher SO<sub>2</sub> levels this approach may not give sufficient reduction in emissions. Consideration may then have to be given to a purpose-built gas cleaning unit. Such a solution was adopted at the cyclone preheater plant at Untervaz in Switzerland. Typical SO<sub>2</sub> emissions were:

2000 - 3000 mg/m<sup>3</sup> (exhaust gas used to dry material in the raw mill)

2500 - 3500 mg/m<sup>3</sup> (raw mill stopped),

compared with a limit of 500 mg/m<sup>3</sup>. Investigations of the raw material used showed that it contained 1 to 1.5% of iron sulphide (FeS<sub>2</sub>). To achieve the limits a scrubbing unit consisting of a circulating fluidised bed was chosen. The absorbing material is calcium hydroxide mixed with some raw meal (to prevent caking). Water is injected to operate the plant as close to the dew point as possible. The absorbent passes with the exhaust gases into an electrostatic precipitator. The characteristics of the unit are as follows:

average SO<sub>2</sub> concentration in exhaust gases - 423 mg/m<sup>3</sup> ;

consumption of calcium hydroxide - 0.9 te/hr for a clinker production of 1900 te/day, that is, a specific calcium hydroxide consumption of 0.01 te/te(clinker);

total power demand - 470 kW .

#### 2.4.2.3 NO<sub>x</sub> Control

The principal specific techniques for controlling technology NO<sub>x</sub> fall into two main categories : Combustion Technology and Selective Catalytic (and Non-Catalytic) Reduction. A combined process of ammonia injection and carbon absorption is also reviewed.

#### **Combustion Technology**

A number of Low NO<sub>x</sub> burners are on the market for use in cement kilns. The principle underlying these burners is that as much of the combustion as possible is carried out under reducing conditions. This is achieved by igniting the fuel with recirculated hot combustion gas, obtained by a reverse flow zone around the extension of the burner centre line. Secondary air is then introduced as gradually as possible. NO<sub>x</sub> reductions of up to 30% are claimed for these burners.

The Polysius company advertise a calciner using a multistage combustion system with up to three fuel burners and two tertiary air inlets. They claim to be able to reduce  $\text{NO}_x$  levels by up to 50% using such a system.

### SCR/SNCR

SCR could theoretically be an effective way to reduce  $\text{NO}_x$  emissions. In this process ammonia is injected into hot gases which are then passed through a catalyst bed where  $\text{NO}_x$  reduction to nitrogen takes place. The reaction should take place in the temperature range of 300-450°C. For the catalyst to be clean and effective it has to be placed after the ESP which would require the heating of the gas to the reaction temperature; this has the disadvantage of increased heat consumption and the associated environmental damage as well as the risk of de-novo dioxin formation.

$\text{NO}_x$  emissions can also be abated by SNCR. This technique involves injecting ammonia as a reducing agent into the flue gas where the reaction takes place at temperatures between 800 and 1100°C (Thomson & Hundebøl, 1992). At lower temperatures a catalyst is needed in addition to the ammonia (SCR). Without the catalyst, unreacted ammonia may escape into the exhaust gases ("ammonia slip") at lower temperatures. At higher temperatures a side reaction which produces additional NO becomes important.

At the Siggenthal works in Switzerland, 25 wt% ammonia water is delivered to the works and stored in two 100 m<sup>3</sup> storage tanks, housed in a concrete basin. The amount of ammonia water injected depends on the levels of  $\text{NO}_x$  in the exhaust gases. The objective is to comply with the set legal limit, 800 mg/m<sup>3</sup> with the injection of the least amount of ammonia. The smaller the difference between the set point for injection and this limit, the lower will be the ammonia consumption. In practice a set point of 790 mg/m<sup>3</sup> was adequate to meet the legal limit.

F L Smidth offer an ammonia injection system for  $\text{NO}_x$  reduction. Rather than have the ammonia water delivered, their system reduces transport costs by having ammonia delivered in liquid form and dissolved in water on site.

A development on the reduction technique using ammonia, is the "3R process" developed by Pilkingtons Glass. This technique was originally developed to reduce  $\text{NO}_x$  emissions from glass furnaces, and has not yet been transferred to other processes. It works on the principle of reducing the  $\text{NO}_x$  produced; this is achieved by introducing fuel into a low oxygen environment thus creating reducing conditions at a high temperature. Air is then introduced under controlled conditions to burn off the CO and other unburnt material at low temperatures. The disadvantage of this process is that it has the potential to trip the ESPs due to high CO levels. It is also not proven on current processes.



**Ammonia Injection (in combination with Carbon Absorption)**

The only known example of this process is at the Siggenthal cement works in Switzerland which uses a 4-stage preheater design with a capacity of 2000 tonne of clinker per day. It is situated in a valley basin where there is very little air movement in unfavourable weather conditions. Its emissions have been reported and are summarized in Table 2.16. (The concentrations are at NTP and 10% oxygen) (Thomsen & Hundebol, 1992).

**TABLE 2.16 : UNABATED EMISSIONS FORM SIGGENTHAL CEMENT WORKS**

Substance	Emission - mill off (mg/m <sup>3</sup> )	Emission - mill on (mg/m <sup>3</sup> )	Limit (mg/m <sup>3</sup> )
SO <sub>2</sub>	1465	560	500
NO <sub>2</sub>	2695	2495	800
NH <sub>3</sub>	80	20	30

NO<sub>x</sub> emissions are abated by means of ammonia injection. The remaining substances are abated using a POLVITEC activated coke filter. After leaving the electrostatic precipitators the gas is passed through two packed bed partition walls. The outer, thinner layer absorbs the bulk of the material, and the final cleaning is achieved in a second, thicker layer. Fresh coke is added to the top of the thicker layer, and the coke withdrawn from the bottom of the thicker layer is added to the top of the thinner layer. The spent coke taken from the bottom of the thinner layer is then added to the kiln fuel, closing the cycle. The harmful material eventually leaves the system in the clinker.

The filter reduces SO<sub>2</sub> concentrations to well below 100 mg/m<sup>3</sup> for all modes of operation (with and without the mill on, with and without replacement fuel), and hence for different levels of unabated emissions. Heavy metal concentrations were reduced to around 2 µg/m<sup>3</sup> even in a mode of operation (mill off, replacement fuel) which showed mercury emissions without abatement of around 30 µg/m<sup>3</sup>. Ammonia emissions were also reduced to a low level, eliminating the risk of ammonia escape from the NO<sub>x</sub> reduction stage.

The cost of the ammonia injection plant and the activated coke filter is quoted as 30 million DM (Rose & Bentrup, 1995). The running costs are said to be "extremely variable" and dependent on the unabated emission levels from the particular mode of operation. The plant was able to offset the costs of this abatement option by being allowed to generate income by burning sewage sludge.

#### *2.4.2.4 Summary of Best Available Control Techniques*

##### ***Best Available Technique to Reduce SO<sub>2</sub>***

The best available technique to reduce SO<sub>2</sub> emission was found to be process modifications such as use of low sulphur raw materials by selecting new quarries, blending feed from different seams of the quarry, and also by actual process modifications. Although FL Smidth claim the wet process can be converted to dry process, they clearly state that the cost of such a conversion would be similar to that of a new dry process plant. The benefits claimed by FL Smidth in converting a wet process to a dry process are applicable only when installing a new dry process on a site with an existing wet process; this is because of the economy of scale in milling capacity.

##### ***Best Available Technique to Reduce NO<sub>x</sub>***

The best available technique to reduce NO<sub>x</sub> was found to be process modifications involving stage calcining to introduce the "3R process" concept. The use of SLF was found to reduce NO<sub>x</sub> emission in cement and lime kilns. The use of SLF is an environmentally friendly way of reducing NO<sub>x</sub>. However, no blanket statement to suggest all forms of SLF will lead to NO<sub>x</sub> reduction can be made. Therefore the approach should be to prove that each SLF blending - or family of blended fuel - can achieve NO<sub>x</sub> reduction.

Although SLF was found to reduce NO<sub>x</sub>, there is evidence to show a slight increase in particulate emission. This could be due to the high Cl<sub>2</sub> content in the system; this makes the dust sticky and ESP less effective.

##### ***Best Available Technique to Reduce Particulates***

The best available technique to reduce the particulate emission from the kiln was found to be ESPs, with improvements to the pre-heater cyclones and ESP's flow patterns and distribution, to capture more particulates. The ESP concept has one inherently good feature, and some bad features. Since each of the parallel flow channels has a number of electrodes in series, any preferential flow between the flow channels will not affect the performance significantly - in addition once the flow among the channels is set there is no inherent fault that can change the flow pattern and as a result it will continue to give good performance. The bad feature is that it will trip on a high CO level or run the danger of a CO explosion in the ESP. The rest of the abatement equipment on the market is susceptible to preferential flow - particularly when the bags in the bag filter house fail as the high gas bypass will reduce the performance significantly. The low gas velocity required in the ESP makes the power consumption low, hence more environmentally friendly. The pressure drop across an ESP is in the order of 15-20 mm H<sub>2</sub>O gauge compared to a pressure drop over a bag filter arrangement of 150-250 mm H<sub>2</sub>O gauge. On average, a pressure drop penalty of about 200 mm H<sub>2</sub>O gauge will be expected. The increase in pressure drop equates to 112 kW electrical power per 1000 tonne of clinker production.

Environmental costs are about 16 tonne of CO<sub>2</sub> and 0.6 tonne of SO<sub>2</sub> per year. Bag filters, however, do have the advantage of being able to absorb SO<sub>2</sub> in the dust collected as a cake on the surface of the bags.

The best available techniques to control particulate releases from other parts of the process include conventional dust containment measures, such as conveyor coverings.

#### ***Best Available Technique to Reduce Heavy Metal***

The best available technique to reduce any trace quantity of heavy metal emission in addition to process control improvement is to improve the particulate collection. There is no suitable technology available to reduce the levels given the quantity of gases produced and the low concentration of particulate which result.

#### ***Best Available Technique to Reduce CO<sub>2</sub>***

The best available technique to reduce the CO<sub>2</sub> emission is to reduce thermal energy consumption by choice of process and/or improving efficiency.

#### ***Best Available Technique to Reduce Dioxin***

The best available techniques to reduce dioxin emission is inhibit its formation by appropriate process control. This includes maintaining low temperatures in the ESPs.

### ***2.5 Economic Impacts of Controlling Releases From Cement Processes***

#### ***2.5.1. Industry Structure***

The UK cement manufacturing industry comprises three principal companies: Blue Circle Cement, Rugby Cement, and Castle Cement. In spite of such a concentrated structure, the market for cement in the UK is highly competitive. Any anti-competitive tendencies have effectively been eliminated principally as a result of the abolition of the Cement Price Agreement (CPA) in the mid 1980s. The recent European Commission investigation into the industry has emphasised the need for confidentiality on commercial basis. Under the CPA the cement industry operated a government approved cartel to ensure sufficient return on investment for the industry and stable prices for the construction sector.

UK production is dominated by Blue Circle Cement, which accounts for just under half of industry output. The approximate market shares of the main producers are shown below:

Blue Circle	49%
Rugby	20%

Castle	22%
Imports	9%

In total there are 20 cement plants in Great Britain, 19 of which are owned by the three main companies noted above, and are affiliated to the British Cement Association (BCA), and one which is owned by Buxton Lime Industries. There are also two plants in Northern Ireland, one of which is independent.

The type of process operated can have an important effect on environmental releases, and in the UK all three main process types are employed. The distribution of process types is as follows:

Process Type	Proportion of UK Output
Dry	49% (70% of which have precalciner)
Wet	21%
Semi wet/semi dry	30%

Source: McLellan, 1995.

The choice of process type is primarily influenced by the local raw materials, rather than company policy. However, even taking account of raw materials, it is unlikely that any new plants based on the wet process will be built in the future, due to their higher specific energy consumption and higher environmental releases.

### 2.5.2 Markets

There are two principal types of cement produced, Ordinary Portland and Rapid Hardening. The manufacturing process is similar for each product and both processes are regulated by HMIP. The rest of this analysis treats cement as a single, homogeneous product.

Cement is sold into four main markets, Ready Mix Concrete (rmc), Bagged Cement, Concrete Products, and Site Mixing. The market shares and key features of these markets are shown in Table 2.17.

TABLE 2.17 : MARKETS FOR CEMENT PRODUCTS

Market	Share	Key Market Features
rmc	45%	Variations in demand are amplified by changes in the construction sector. During times of recession, construction projects shift away from those with high concrete intensity. Cement is bought directly from the cement producers, by the large construction materials companies such as RMC, Redland, ARC and Tarmac. Demand is heavily concentrated with the top third of customers accounting for over 80% of rmc demand.
Bagged	27%	Bagged cement sells at a 15-25% premium compared to bulk prices; but its share of the market has decreased in recent years and it is not likely to increase again. Bagged cement is predominantly sold to builders merchants, for trade use, and the DIY market. A small proportion of bagged cement is also sold to the large DIY stores.
Concrete products	25%	Concrete products include tiles, blocks, pipes, slabs etc. Concrete product manufacturers include the large building materials companies, (which often also supply rmc), such as RMC and Redland, and specialist producers, which tend to concentrate on large pre-cast concrete pieces such as bridge sections. The latter include companies such as Bison and Tarmac Building Materials.
Site mixing	3%	Site mixing is only a small component of the market.

Source : James Capel, 1995, BCA, Cement Operators

In general, the market for cement is dominated by a relatively small number of large firms in the construction materials sector. These firms operate very price-conscious purchasing policies, and are able to exert significant pressure on prices charged for cement. Due to these demand-side pressures and the threat from imports, prices of cement have been falling for a number of years. UK prices have decreased by about 40% in real terms since 1986, although they appear to have stabilised in 1995. Financial analysts indicate that the price of bulk cement is currently around £40/tonne following one of the first price increases a number of many years of £2.75/tonne (a rise of 4.5%) in March 1995. The long-term fall in prices, has been accommodated in part by the industry through significant improvements in production and distribution efficiency.

### 2.5.3 International Competition

International competition is the main competitive threat to the UK cement industry. Exports are negligible. The key features of the UK's exposure to imports are:

- Imports currently account for around 9% of UK production (8% of the UK market). However, imports as a share of UK production, have declined from around 13% in 1990. Cement is imported principally from Greece and Eastern Europe, in particular the Baltic States.
- Cement is imported into the UK both by UK producers and by overseas exporters. During the 1980s when UK cement demand exceeded domestic production capacity, over 70% of imports were brought into the UK through domestic producers, for example, through Blue Circle's Northfleet plant. Castle Cement also has an import terminal based in the London docklands. At present two out of the three main Greek exporters, have import terminals in the UK.
- The capacity available to supply the UK from overseas plants is substantial, with a number of foreign producers able to use export markets as outlets for spare capacity.
- The availability of cement from independent importers has a strong influence on the price of cement in the UK. Indeed, one UK cement company has adopted a policy of pricing its product at the same price as imports. Even though UK producers can import cement through their own terminals, margins on imported product are less than for cement produced in the UK. Further imports would thus be damaging to the UK cement industry.

### 2.5.4 Financial Performance of UK Cement Companies

Table 2.18 shows the performance of Castle Cement and Rugby Cement over the period 1991-1994. Accounts for Blue Circle Cement are not available as they are subsumed into the consolidated accounts of Blue Circle Industries. Public statements (*FT*, 8th September 1995) indicate that Blue Circle's UK cement operating profits rose by almost 8% to £30.4m in 1994 on a sales increase of 4.2%. Overall it appears that profitability in the industry is low, with pre-tax, (post-interest) profits as a proportion of turnover ranging between 3% and 6%.

Return on capital employed (ROCE), which is widely used to indicate the financial performance of a company or sector, is more variable. ROCE at Castle averaged 4% to 8% between 1991 and 1994, in contrast to Rugby's estimated 20%. The high figure for Rugby Cement, however reflects the statement of profits before interest (whereas Castle's are taken after interest), and the relatively low asset base of Rugby's Cement operators. A large proportion of the assets at Rugby are old and have a low book value, which inflates the ROCE ratio. In contrast, Castle has made substantial investments in recent years and the book value of its assets is higher. An average

TABLE 2.18 : PERFORMANCE OF UK CEMENT COMPANIES

Company	Turnover (£ million)				Profit (£ million)				Profitability			
	1991	1992	1993	1994	1991	1992	1993	1994	1991	1992	1993	1994
Rugby Cement <sup>(1)</sup>	128.0	119.0	116.5	131.4	19.1	16.8	17.7	16.8	15%	14%	15%	13%
Castle Cement <sup>(2)</sup>	157.0	142.0	140.0	147.0	4.7	2.0	3.9	8.8 <sup>(3)</sup>	3%	1%	3%	6%

Source : Companies House, 1995

Notes :

(n/a) not available

(1) Profits are stated before tax and interest

(2) Profits are stated before tax.

(3) EC fines excluded

ROCE value for the industry is estimated by financial analysis to be the region of 10%, based on assets valued at historic cost and profits taken after tax.

#### *2.5.5 Competition from Substitutes*

Competition to cement exists in the form of non-concrete construction materials and direct substitutes for cement in concrete. Competition from alternative construction materials is present in certain markets such as building frames (steel) and road surfacing (tarmac).

The main threat however to cement from substitutes is in replacements for cement in concrete. Pulverised fly ash (PFA) and blast furnace slag can replace up to 30-35% of cement in certain types of concrete. However, the widespread use of these materials, is limited by the lower quality of concrete which is produced from cement replacements - (for example, a higher blast furnace slag content in the concrete lengthens the hardening time), and by the limited availability of substitutes of suitable quality (for example, much PFA has too high a carbon content, and most blast furnace slag is not suitable for use in concrete because of the way in which it is cooled as it leaves the furnace).

#### *2.5.6 Costs of Controlling Releases*

A number of techniques can be used to reduce releases from cement processes. The most applicable techniques have been profiled in Appendix B.6 together with the associated capital and operating costs. They all concentrate on controlling releases to air, since these are the principal environmental impacts from cement processes, and they are categorised according to the substance abated: particulates, SO<sub>2</sub>, NO<sub>x</sub> and metals/dioxins/others.

The costs presented are estimates for a typical 2,000 tonnes per day (tpd) dry plant with pre-heater and pre-calcination operating 350 days a year. Some plants may have lower operating days per year. At these plants though the effect on unit costs of lower throughputs will be off-set to some extent by longer depreciation periods. Capital costs are quoted for delivered equipment excluding duct work and civils. The cost per tonne of cement is calculated first by annualising the capital and operating expenditure, and dividing by the yearly production. A discount rate of 10% has been assumed for all capital equipment, which closely corresponds to the average cost of capital (including opportunity costs) used by companies in the industry.

The life of pollution abatement equipment has been assumed to be 10 years, with the exception of materials handling measures which have been depreciated over 20 years. The main items of cement manufacturing equipment, such as the kilns, typically have useful lives of around 20 years. The shorter depreciation period for pollution control equipment reflects the generally smaller scale of this type of equipment.



Table 2.19 summarises the costs of the various control options. Cement kilns are fuelled principally by coal. The main alternative to coal is pet-coke which is at least 20% to 40% cheaper per unit of energy but has the potential to generate higher releases of SO<sub>2</sub> than coal. However, the potential to increase the use of pet-coke is limited, due to the limited world supply (pet-coke is principally produced as a by-product of gasoline refineries in the US) and growing world demand for the fuel, driven by rising world prices of steam coal. Control options include fuel switching, to reduce releases.

The use of alternative fuels can reduce releases of certain substances from the process. Whilst some of these fuels are more expensive than conventional coal, (eg, low sulphur pet-coke), lower cost alternatives can also be used. Those fuels which offer the greatest potential for future savings and reducing releases are secondary liquid fuel and waste tyres. These alternatives are currently being evaluated by the UK cement industry and HMIP.

#### *2.5.7 Industry Costs of Control*

In order to assess the economic implications of additional pollution control requirements on the cement industry, it is first necessary to determine the total net cost burden on the industry. This takes into account all the main costs associated with reducing the industry's impact on the environment, together with any savings which may be derived from environment related activities, (for example, the use of cheaper fuels). This cost is dependant on a number of variables, the most important of which are:

- the proportion of industry required to install each type of technique
- the price differential between coal and substitute fuels
- the extent to which substitute fuels are used.

**TABLE 2.19 : COSTS OF TECHNIQUES TO CONTROL RELEASES FROM CEMENT MANUFACTURING PROCESSES (EXCLUDING CIVIL WORK AND DUCTING) <sup>(5)</sup>**

Technique	Capital cost (\$ million)	Operating cost (\$'000)	Annualised cost (\$'000)	Cost per tonne (\$)
ESP Replacement <sup>(1)</sup>	2-4	100	430-750	0.5-1.0
Bag Filter <sup>(2)</sup> Replacement	3-6	700	1,190-1,680	1.7-2.4
ESP <sup>(1)(3)</sup> /Bag Filter Up- grade <sup>(2)(4)</sup>	0.8-1.2	100	230-300	0.3-0.4
Materials Handling Measures	2.3-5	-	260-580	0.4-0.8
Selective Quarrying	0.2	100	130	0.2
Lime addition	0.5	100-750	180-830	0.25-1.25
FGD (dry) (lime injection filter)	4-8	900	1,550-2,200	2.2-3.1
FGD (wet)	8-10	2,900	4,200	6.0-6.4
Fuel Selection (low sulphur coal - 1% content compared to a usual 1.4%)	-	660-1,130	660-1,130	0.9-1.6
Fuel Selection (SLF & waste tyres)	n/a	n/a	n/a	0.1-1.1 saving
Combustion Control (low NOx burners)	0.75	50 - 90	170 - 210	0.25 - 0.3
Staged combustion	1.5	750	995	1.4
SNCR	0.8 - 1.5	150 - 350	280 - 590	0.4 - 0.8

Source L UK Overseas Operators : Equipment Suppliers

- Note:
1. ESP improvement refers to kiln emissions
  2. Bag filter improvement refers to other contained emissions
  3. ESP upgrade includes the addition of more elements to improve gas flows.
  4. Bag filter upgrade includes the addition of extra banks of filters plus associated design work.
  5. For a reference plant defined as a dry process, with pre-heater and pre-calcination.

These techniques are profiled in more detail in Appendix B.6.

The impact of different scenarios involving these variables, on the net costs to the industry is shown in Table 2.20. Costs and savings are expressed in terms of pounds per tonne of cement.

The low cost scenario represents a minimal implementation of particulate controls at all cement plants, involving the refurbishment of existing ESPs and filter bags, and the installation of SO<sub>2</sub> and NO<sub>x</sub> controls on 20% of cement production. The medium cost scenario assumes that half of cement production is controlled with new ESPs and half with refurbished ESPs while bag filters, and NO<sub>x</sub> and SO<sub>2</sub> controls are installed on 60% of production. The high cost scenario assumes that all UK cement production plants are fitted with new ESPs and with SO<sub>2</sub> and NO<sub>x</sub> controls. Gross industry average control costs amount to £0.8/tonne, £1.7/tonne and £2.6/tonne under each of the scenarios respectively.

Cost savings may realistically be achieved in the cement industry through the greater use of alternative fuels such as: SLF and waste tyres. The cost to cement producers of using SLF is not known with any degree of accuracy, but in the medium term (2-5 years) it is likely to be between 50% and 80% of the cost of coal, per unit of energy. Prices are thought to be somewhat lower at present, but if the immediate political and environmental concerns associated with the fuel are overcome prices can be expected to rise until the total net costs - including burner conversions - of using SLF approach those of using coal and pet-coke, although a margin will still be required to overcome any residual political and environmental doubts associated with the fuel.

No data has been made available on the large scale cost of using waste tyres in cement kilns. Even though there are potential operational difficulties of maintaining an acceptable clinker quality when firing with tyres - due to the metal content - costs are still likely to be lower than for other alternative fuels, estimated at around 30% of the cost of coal. Total substitution of these fuels is assumed to be 5%, 10% and 15% under the three scenarios. More than 15% substitution across the whole industry is considered unlikely due to the limited availability of these fuels relative to coal.

Total cost savings from fuel switching options under the low, medium and high scenarios are £0.2-0.4/tonne, £0.5-0.7/tonne and £0.7-1.1/tonne.

The net costs of reducing releases from cement processes are summarised under three consolidated scenarios in Table 2.21. Depending on the plant/company affected, the costs of installing process changes and abatement measures can be partially off-set against savings made elsewhere in the process as a result of environmental improvement measures.

**TABLE 2.20 COSTS OF IMPROVING ENVIRONMENTAL CONTROL IN THE UK CEMENT INDUSTRY**

**COST OF CONTROL**

TECHNIQUE	COST/TONNE (\$)	SCENARIO		
		low	medium	high
Proportion of Industry Covered		0%	50%	100%
ESP / BF replacement (including IPR 3/1 req'ts)	0.8 (1)	0.00	0.40	0.80
Proportion of Industry Covered		100%	50%	0%
ESP / BF refurbishment (including IPR 3/1 req'ts)	0.4 (1)	0.40	0.20	0.00
INDUSTRY COSTS OF PARTICULATE CONTROL		0.40	0.60	0.80
Proportion of Industry Covered		20%	60%	100%
Lime injection	0.75 (1)	0.15	0.45	0.75
Combustion control	0.4 (1)	0.08	0.24	0.40
SNCR	0.6 (1)	0.12	0.36	0.60
TOTAL INDUSTRY COSTS OF CONTROL	2.95	0.75	1.65	2.55

**SAVINGS FROM FUEL CHANGES (potential changes from 1994)**

	Price of fuel as a proportion of cost (per unit of energy)	Cost Saving/tonne cement (£ 100% substitution) (2)	Proportion of Fuel Substitution (Industry-wide)			Reduction in Average Manufacturing Costs (\$/tonne)		
			low	medium	high	low	medium	high
SLF (low price differential)	80%	2.45	3%	6%	9%	0.07	0.15	0.22
SLF (high price differential)	50%	6.13	3%	6%	9%	0.18	0.37	0.55
Tyres	30%	8.58	2%	4%	6%	0.17	0.34	0.51
TOTAL (low SLF price differential)			5.0%	10.0%	15.0%	0.2	0.5	0.7
TOTAL (high SLF price differential)			5.0%	10.0%	15.0%	0.4	0.7	1.1

**NET COSTS OF IMPROVING ENVIRONMENTAL CONTROLS (\$/TONNE OF CEMENT)**

FUEL SUBSTITUTION		COST SCENARIO		
		low	medium	high
low fuel substitution	(low SLF price differential)	0.5	1.4	2.3
	(high SLF price differential)	0.4	1.3	2.2
medium fuel substitution	(low SLF price differential)	0.3	1.2	2.1
	(high SLF price differential)	0.0	0.9	1.8
high fuel substitution	(low SLF price differential)	0.0	0.9	1.8
	(high SLF price differential)	-0.3	0.6	1.5

**NOTES**

1. See text for source and calculations
2. Based on total manufacturing costs of \$35/tonne, 35% of which are attributable to kiln fuel

TABLE 2.21 : NET COSTS OF CONTROLLING RELEASES FROM CEMENT PROCESSES

Scenario	Cost of Control (\$/tonne cement)
low cost	-0.3 - 0.5
medium cost	0.6 - 1.4
high cost	1.5 - 2.3

## 2.6 Summary of Economic Impacts of Controlling Releases

The state of the UK cement industry is summarised as follows:

- Stabilised demand. Following the peak in cement demand in 1989 at over 17 mte/y, and the subsequent sharp decline to around 12.5 mte/y in 1992, demand then increased in 1993 and 1994 and is expected to continue to rise gradually over the next decade (*UK cement operator's forecasts*).
- Strong potential competition from cheap imports. Although imports at present constitute less than 10% of UK demand, the threat of imports from plants in Greece and Eastern Europe, effectively creates a ceiling on prices in the UK market. There is therefore no opportunity for UK cement producers to pass on any additional costs through higher prices.
- Low investment in new plant and equipment over the last 10 to 20 years. Only one new works has been built since the early 1970s namely Castle Cement's Ketton plant which was constructed in the 1980s. This lack of investment is principally due to the pressure from imports which has reduced prices in the sector to the extent that the expected returns on control were not sufficient to support the large investments required in new plant and machinery by the other two main producers Rugby and Blue Circle Cement.
- Low profits. Profits before tax (after interest) represent between 3% and 6% of turnover, although profits of all three companies have increased in recent years as a result of improvements in efficiency.
- Low expected return on new capital invested in the industry. The industry is highly capital intensive and all three companies report lower rates of return on capital invested (using whatever indicator of performance is preferred by the company) than is required by shareholders.

As a result of the relatively low expected return on investment in the industry, expenditure on environmental projects has been, (and continues to be) limited to a low level, sufficient to

maintain existing levels of business activity. The scale of this expenditure is typically equivalent to around £0.5 per year per tonne cement produced. Any further investment in environmental projects would reduce the return on investment further below the rate of return required by shareholders. As a result, firms would opt to import cement, often through their own port terminals. Although this would maintain sales, it generates less profit and could eventually result in the closure of the less profitable plant(s).

Operating costs of these investments in environmental controls are typically similar in magnitude to the annualised capital costs. The resultant total costs of control which the industry can afford without a significant erosion of return on investment are therefore estimated at around £1.0/tonne. This scale of increase would allow expenditure by the industry on pollution control in line with the levels defined in the combined "low" scenario. Any further controls imposed on the industry could result in an increase in imports or in the closure of one or two of the least efficient plants. The resultant environmental benefits would then need to be judged against the associated economic costs.

### 3. LIME PROCESSES

#### 3.1 The Sector

##### 3.1.1 Sector Description

Companies producing lime in the UK are RMC, Buxton Lime Industries, Southern, Redland, Singleton Birch, Tilcon, British Sugar, British Steel, and ARC. The location of plants, the kiln type, and daily capacity are summarized in Table 3.1.

**TABLE 3.1 : SUMMARY OF UK LIME PRODUCTION**

Company	Plant Site	Kiln Type	Number	Capacity (te/day)
RMC	Hindlow	not available	not available	not available
Buxton Lime Industries	Hindlow	Maerz		
	Tunstead	rotary	2	2 x 240
		shaft	4	4 x 240
Southern ARC	Cheddar	rotary	1	552
Redland	Thrislington	rotary	3	2 x 624, 1 x 1920
	Whitwell	rotary	2	2 x 960
Singleton Birch	Melton Ross	Maerz	4	3 x 312
Tocon	Swinden	shaft	2	2 x 2400
British Sugar	Allscott	shaft	1	96
	Barnsley	shaft	1	264
	Bury St Edmund	shaft	2	2 x 168
	Cantley	shaft	1	120
	Ipswich	shaft	1	144
	Kidderminster	shaft	1	168
	Newant	shaft	1	768
	Wissington	shaft	2	364, 144
	York	shaft	2	144, not available
British Steel	Shapfell	Maerz	4	1632 (total)

Source : HMIP, 1995, Central Register

### 3.1.2 Process Description

The lime manufacturing process is essentially the same as the calcination stage of the cement manufacturing process. Calcium or magnesium carbonate is heated to liberate carbon dioxide and leave the oxide. The temperatures used are usually between 800°C and 1500°C although sometimes a significantly higher temperature is required such as for the dead-burnt dolomite process.

Calcium or magnesium carbonate of high purity (96-98%) is quarried and transported to a kiln for the heating process. There are several types of kiln in use, the most common of which are the rotary kiln, and the vertical shaft kiln. All these kilns take coarse stone (>10 mm) although the rotary kiln with cyclone preheater can accept a feed material of 0-2 mm diameter, which can be waste from other operations within the lime production process. 0-2 mm material may also be processed in a flash calciner, a technique which was originally developed in the cement industry.

The burnt lime or calcium oxide produced by the kiln can then be hydrated to form slaked lime or calcium hydroxide if required; this is known as slaking and involves the slow addition of water in a hydrator which consists of pairs of contra-rotating screw paddles to agitate the lime. The reaction is very exothermic, and about twice the stoichiometric quantity of water is added to absorb the heat generated by boiling. A partially fluidized bed is created by the vigorous reaction and dust is entrained with the steam given off and discharged to atmosphere. Sometimes this dust is collected in a wet scrubber. The milk of lime suspension which is collected can be returned to the hydrator.

The hydrated product is then finely ground and air swept to a rotary separator from which the coarse fraction is recycled for further grinding and the fine fraction is sent to storage silos before final dispatch. There is the obvious potential for fugitive dust emissions during this process.

Each of the main types of kiln are now discussed in turn. Schematic diagrams of these processes are shown in Figures 3.5 to 3.7.

#### 3.1.2.1 Rotary Kiln

The kiln is inclined at a slight angle (1-2 degrees) to the horizontal. Limestone is fed in at the higher cooler end and fuel is introduced at the lower hotter end. The kiln rotates and this combined with the slope moves the limestone slowly towards the flame. After passing through the burning zone, the burnt lime begins to cool and descends from the kiln into a cooler.



FIGURE 3.5 : ROTARY LIME KILN : SCHEMATIC DIAGRAM OF PROCESS

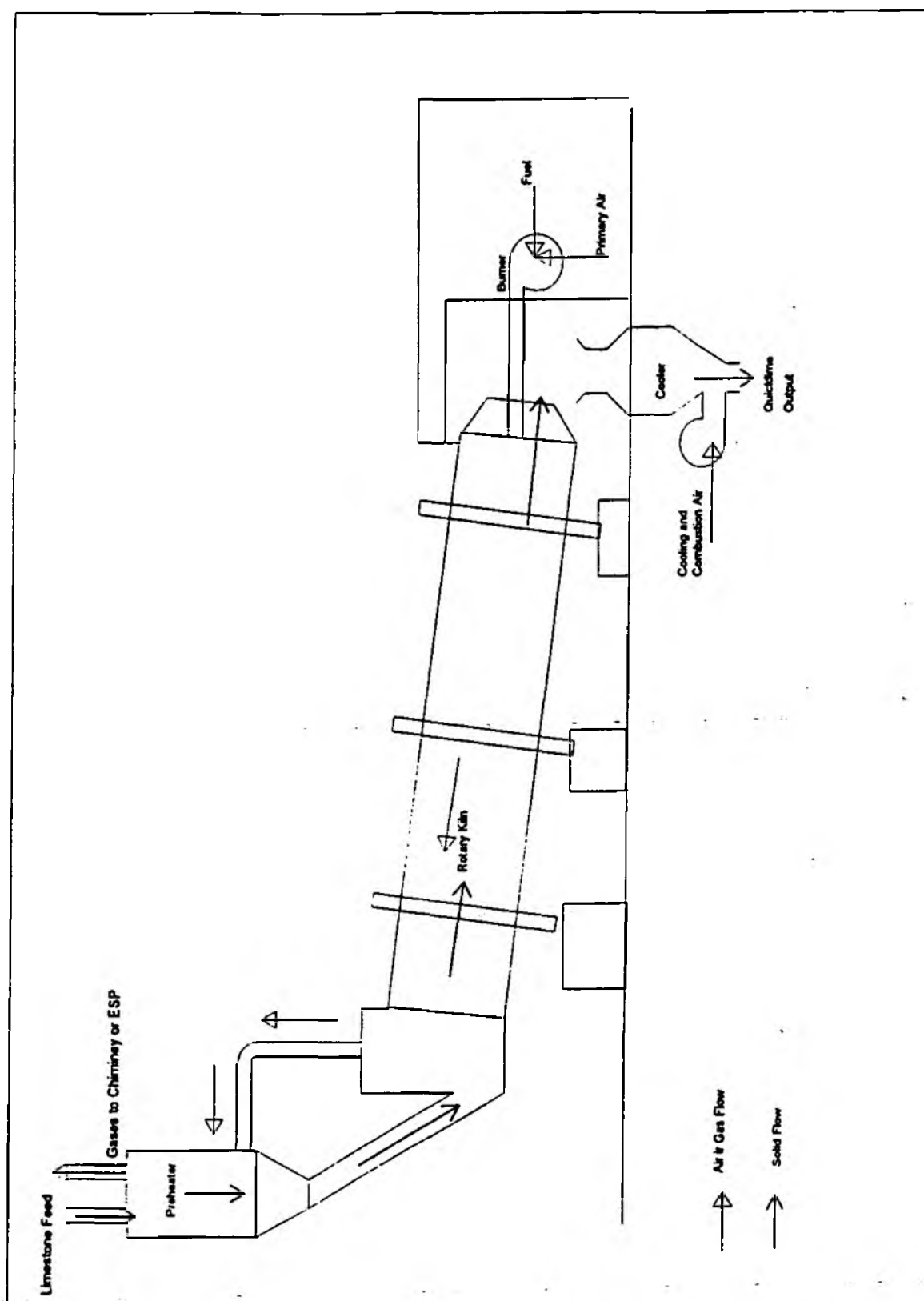


FIGURE 3.6 : VERTICAL SHAFT KILN : SCHEMATIC DIAGRAM OF PROCESS

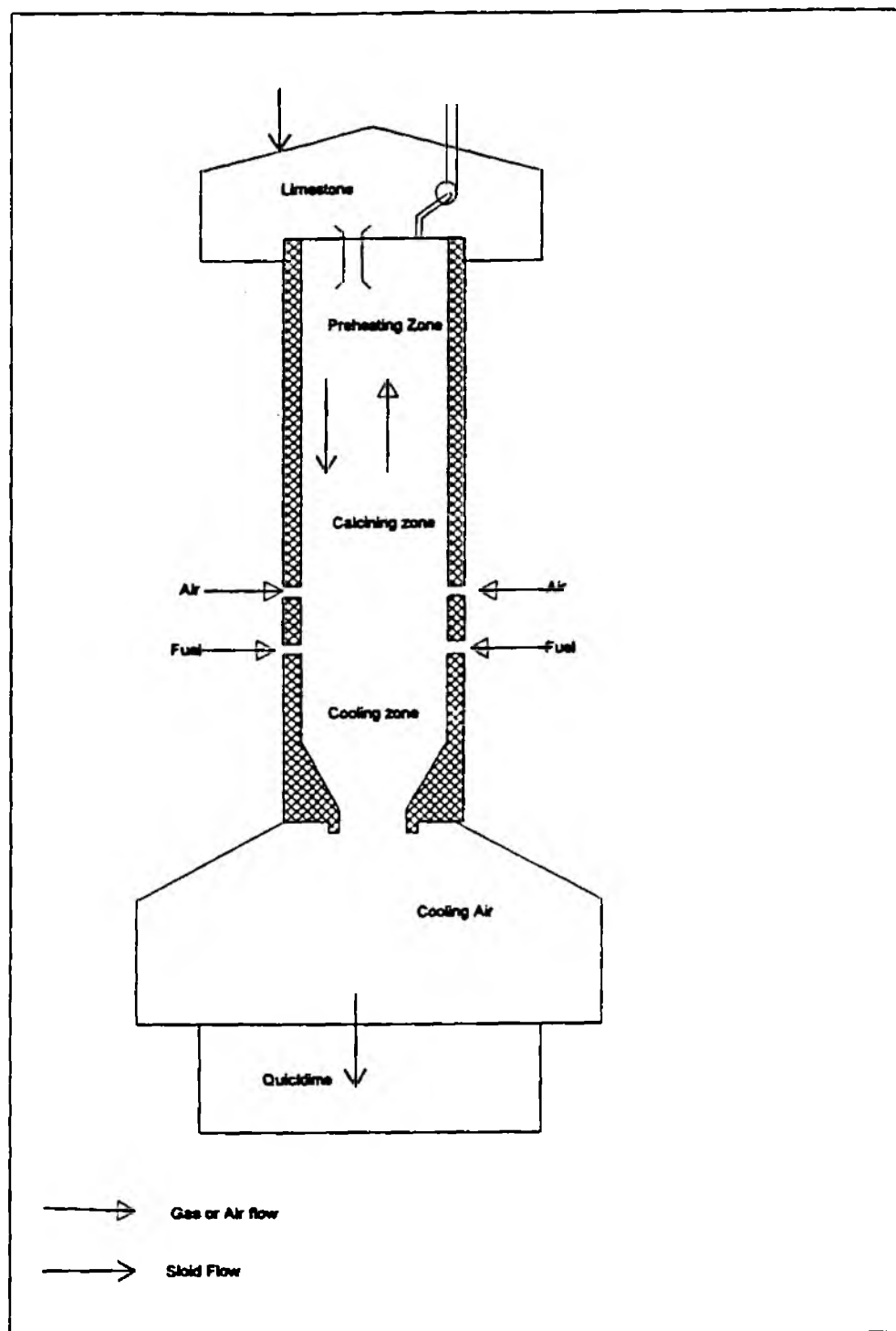
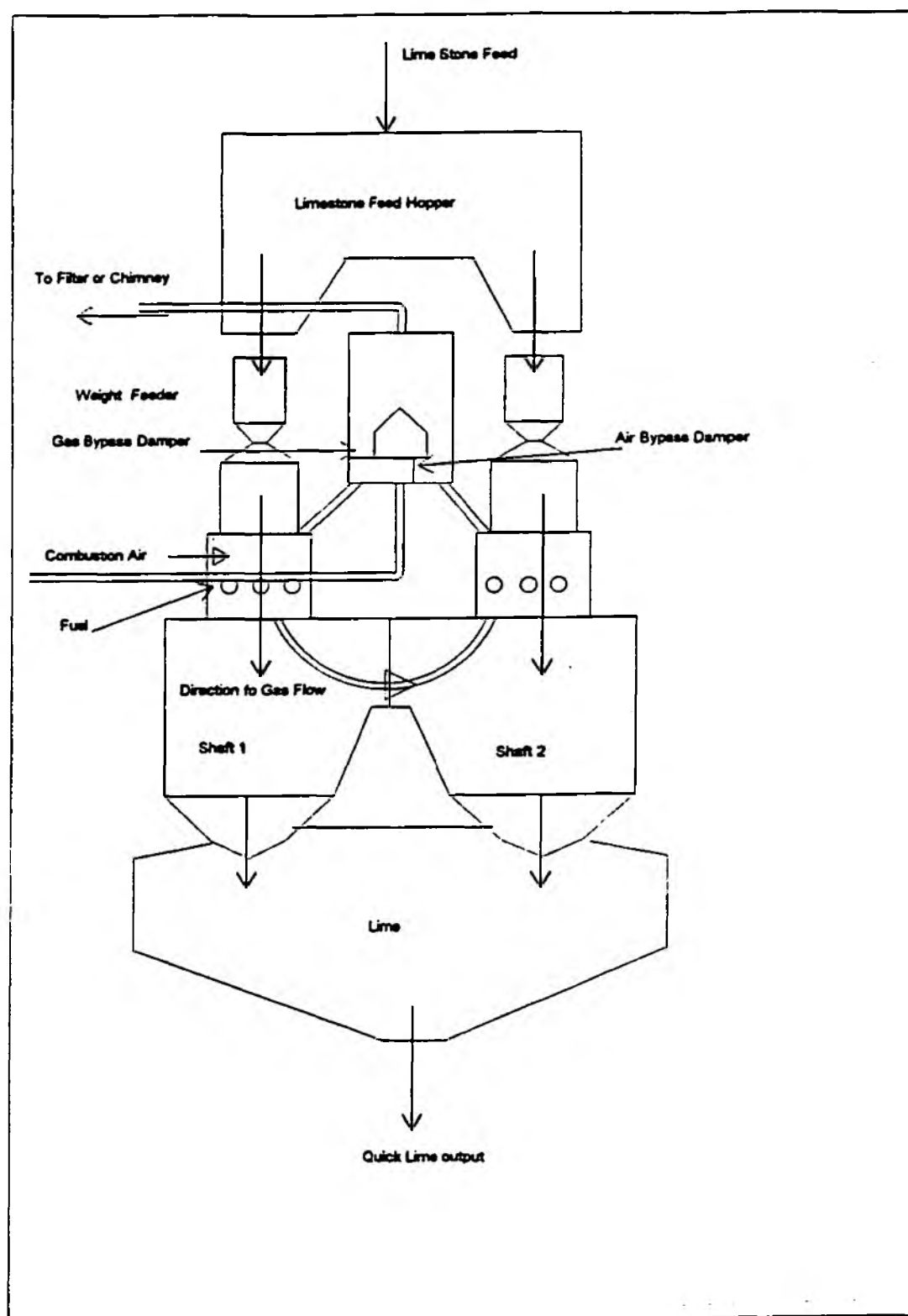


FIGURE 3.7 : MAERZ KILN : SCHEMATIC DIAGRAM OF PROCESS



Modern processes incorporate a preheater. This is a chamber into which the limestone is fed and heated by hot kiln gases being drawn up through it by an induced draught fan. This also has the added effect of drawing ambient the air through the burnt lime in the cooler to assist with cooling.

The lime is then transferred from the cooler to dry storage silos from where it either undergoes further processing or is dispatched directly to the end-user .

Compared with shaft kilns, costs of rotary kilns are higher due to the greater energy consumption per tonne of lime produced. However, they have the advantage of being able to produce a good quality, uniform product which can be achieved even with low cost fuels. A further advantage is that if coal is used to fire the kiln, sulphur can be trapped in the preheater, thus reducing final SO<sub>2</sub> releases.

Common fuels used in lime kilns include natural gas, liquefied petroleum gas (LPG), coal, or heavy fuel oil. Alternative fuels, such as Secondary Liquid Fuels (SLF) have been trialed on a few kilns, but are not in widespread commercial use.

#### *3.1.2.2 Vertical Shaft Kiln (Maerz or Parallel Flow Regenerative Kiln)*

In this type of kiln, lump limestone is introduced at the top via a bell housing with an air lock. The burners are arranged in the kiln to give a full range of directions of fire and thus maximize the contact of hot gases with the stone.

The burnt lime is extracted from the bottom via a grate system and double air lock flap gates. The throughput of this system determines the rate of descent of feed through the kiln and length of time in the burning zone.

An induced draught fan draws the combustion air up over the burnt lime emerging from the burning zone to cool the lime and preheat the air; similarly, the fan draws the hot exhaust gases over the cold feed to cool the gases and preheat the feed.

A natural draft instead of a fan is common on older and smaller kilns of this type. For these kilns the limestone and fuel - coal or petroleum coke - in alternate layers are charged in batches about every two hours. The product is removed in batches from base of the kiln after having taken about a week to move down the kiln.

In order to improve fuel consumption various improvements to the above systems have been made. One is the use of two or even three interconnected shafts to maximize the heat extracted from the exhaust gases and to minimize leakage during charging by burning in a shaft that is not being charged.

### **3.1.2.3 Rotating Hearth Kiln**

This type of kiln was designed to produce pebble lime but has now almost fallen out of use. The limestone is heated by multiple burners as it rotates in the annular hearth. The combustion air is preheated by surplus heat in exhaust gases. This kiln has the advantage that losses of usable burnt lime due to abrasion and pressure are lower than for other kiln types.

### **3.2 Impacts on the Environment**

The general environmental impacts of lime processes are very similar to those of cement processes, and are described and assessed in detail in Appendix A. The principal impacts specific to lime processes are summarised below.

- Releases of fine, alkaline and reactive particulates to air in the near field, potentially extending to the far-field, due to the fine nature of the dust;
- Releases of SO<sub>2</sub> and NO<sub>x</sub> to air in the fair-field;
- Dioxins from burning alternative fuels;

Other releases which should be considered, but are not as significant include:

- General impacts of quarrying and transport operations.
- CO<sub>2</sub> releases from fuel combination.
- Potential releases to water from site run-off and slaking processes.

### **3.3 Achievement of Current Standards**

The HMIP's Chief Inspector's Guidance to Inspectors for the lime manufacture (HMIP, 1992b) gives limits for releases into air for new plant and existing plant; they are shown in Table 3.2.

**TABLE 3.2 : LIMITS SPECIFIED BY HMIP FOR RELEASE TO AIR FROM LIME MANUFACTURE**

Specified Substance		Limit (mg/m <sup>3</sup> )
particulate matter	limestone preparation	100
	kilns <sup>(a)</sup>	50
	milling and grinding	50
	lime slaking	100
	all other contained sources	50
oxides of sulphur (expressed as SO <sub>2</sub> )		750
oxides of nitrogen <sup>(b)</sup> (expressed as NO <sub>2</sub> )		1800

- (a) for existing kilns this standard should be achieved by 1 April 1998 unless they are modified in order to increase output or have their arrestment equipment totally replaced in which case the limit will have immediate effect
- these limits may not be appropriate for some older types of shaft kiln and the Inspector should base any requirements upon the scale and type of operation
- (b) a higher release limit may be considered in cases where the applicant can demonstrate to the satisfaction of the Inspector that, owing to the sulphur content of the raw materials (excluding fuel), it would entail excessive cost to achieve the limit specified

The following are prescribed substances for release into air:

particulate matter,  
 oxides of sulphur and other sulphur compounds,  
 oxides of nitrogen,  
 oxides of carbon.

For releases into water there are no prescribed substances and for releases into land the prescribed substances are alkaline earth metal oxides.

### 3.3.1 Actual Releases

Data supplied by HMIP on releases from lime production and processing have been surveyed. The examples selected for presentation here are those where there are sufficient data available to enable a meaningful comparison to be made. These comprise the kiln exhaust emissions from four lime works: two with Maerz and two with rotary kilns. The kiln details are given in Table 3.3.

TABLE 3.3 : DETAILS OF LIME KILNS FOR WHICH EMISSION DATA WAS OBTAINED

Works	Kiln	Type	Capacity (te/hr)
Thrislington	T1	rotary	26
	T2	rotary	26
	T3	rotary	80
Cheddar	1	rotary	23
Melton Ross	1	Maerz	13
	2	Maerz	13
	3	Maerz	13
Shapfell	1	Maerz	12.5
	2	Maerz	12.5
	3	Maerz	12.5
	4	Maerz	12.5

The following sections present and discuss the data for each pollutant from the selected kilns. The abatement technique and the fuel type are given after the works' names.

#### 3.3.1.1 Particulate Releases

The measured particulate concentrations (STP, dry gas, 11% oxygen) are given in Table 3.4 for each of the above kilns, in terms of the mean and maximum reported values. The number of data points is given in parentheses after the mean value where it is known.

These data indicate that the burning of SLF in lime kilns increases the dust emissions by a factor of between three and four. It must be stressed however that this conclusion is based on only a few data points, and further monitoring and analysis of results would be needed to confirm it. The gas-fired kilns appear to have little difficulty meeting a 100 mg/m<sup>3</sup> limit on particulate emissions, and most of the samples are well below 50 mg/m<sup>3</sup>.

**TABLE 3.4 : MEASURED PARTICULATE RELEASES FROM SELECTED LIME KILNS**

Works	Kiln	Mean (mg/m <sup>3</sup> ) (no. of points)	Max (mg/m <sup>3</sup> )
Thrislington (ep,SLF) Abatement : ESP Fuel : Coal/Pet-coke	T1	111 (not given)	485
	T2		
	T3 (30% SLF)	58 (not given)	225
Cheddar Abatement : ESP Fuel : Gas	1	2.6 (4)	4.4
Melton Ross Abatement : Wet Scrubber Fuel : Gas	1	49 (6)	71
	2	21 (6)	39
	3	22 (6)	63
Shapfell Abatement : Wet Scrubber Fuel : Gas	1	20 (1)	20
	2	19 (2)	27
	3	8 (2)	9
	4	21 (2)	28

Source : UK Operators

### 3.3.1.2 NO<sub>x</sub> Releases

The results for nitrogen oxide concentrations are given in Table 3.5. The indication from these results is that the rotary kilns are close to and sometimes above the 1800 mg/m<sup>3</sup> limit, while the Maerz kilns are almost two orders of magnitude below.

### 3.3.1.3 SO<sub>2</sub> Releases

The results for sulphur dioxide concentrations are given in Table 3.6. The only results where SO<sub>2</sub> is reported (Thrislington) show a large and unexplained variation. At Cheddar, SO<sub>2</sub> was monitored for but not found in significant quantities - a fact attributed to the very low sulphur content of the natural gas fuel and the nature of the raw materials. From these results it appears that the use of coal and pet-coke has a significant influence on SO<sub>2</sub> emissions, although without analysing the sulphur content of the feed stock this cannot be verified.



TABLE 3.5 : MEASURED NO<sub>x</sub> RELEASES FROM SELECTED LIME KILNS

Works	Kiln	Mean (mg/m <sup>3</sup> ) (no. of points)	Max (mg/m <sup>3</sup> )
Thrislington Abatement : ESP Fuel : Coal/Pet- Coke	T1	1164 (not given)	2369
	T2	1522 (not given)	1522
	T3 (30% SLF)	1419 (not given)	2259
Cheddar Abatement : ESP Fuel : Gas	1	1405 (2)	1694
Melton Ross Abatement : wet scrubber Fuel : Gas	1	not given	not given
	2	not given	not given
	3	not given	not given
Shapfell Abatement : wet scrubber Fuel : Gas	1	41 (1)	41
	2	28 (2)	30
	3	19 (2)	20
	4	31 (2)	34

**TABLE 3.6 : MEASURED SO<sub>2</sub> RELEASES FROM THE SELECTED LIME KILNS**

Works	Kiln	Mean (mg/m <sup>3</sup> ) (no. of points)	Max (mg/m <sup>3</sup> )
Thrislington Abatement : ESP Fuel : Coal/Pet- Coke	T1	1308 (not given)	2399
	T2		
	T3	9.1 (not given)	13.2
Cheddar Abatement : ESP Fuel : Gas	1	none detected	none detected
Melton Ross Abatement : wet scrubber Fuel : Gas	1	not given	not given
	2	not given	not given
	3	not given	not given
Shapfell Abatement : Wet Scrubber Fuel : Gas	1	not given	not given
	2	not given	not given
	3	not given	not given
	4	not given	not given

#### 3.3.1.4 Heavy Metals and Dioxins

No measurements of heavy metal concentrations in lime kiln exhaust gases were reported in the data sent to HMIP and surveyed in the current study. The only reported dioxin concentrations were for the SLF trials on the Thrislington kiln T3. The mean concentration (TEQ) was reported as 0.32 ng/m<sup>3</sup>, with a maximum of 0.42 ng/m<sup>3</sup>. These releases are of a similar order of magnitude as those from current kilns and lime kilns should therefore be subject to the same dioxin and heavy metal monitoring and associated limits as cement kilns.

#### 3.4 Review of Available Techniques

The techniques currently in use in the following countries have been assessed: UK, USA, and most European countries. As in the assessment of cement processes, general techniques refer to those which can affect a range of pollutants, whilst specific techniques are designed to abate particular substances.

The following two sections and discuss general and specific techniques respectively. Appendix C describes the applicability of each technique to lime processes in more detail. Appendices C.2 to C.4 review the techniques for controlling releases from lime processes in terms of Raw Material

Options (C.2), Fuel Options (C.3) and Abatement Options (C.4) respectively in the context of the Elimination, Minimisation and Render Harmless criteria applied by HMIP in the assessment of BATNEEC.

### *3.4.1 General Techniques*

General techniques include kiln type, kiln running and fuel selection. These techniques are summarised in Table 3.7.

#### *3.4.1.1 Type of Kiln*

There are basically two types of kiln in operation namely vertical shaft and rotary. The vertical shaft kilns include the Maerz kiln which is one of the most thermally efficient designs. In these kilns the material flows vertically downwards passing the burning zone. The burners are situated about half way up the kiln. The slow movement of the feed reduces the risk of material degradation and dust formation. This also lends itself to the installation of burners at different levels allowing combustion control or with the possibility of creating reducing conditions to decrease NO<sub>x</sub> emissions. The direct firing of the burners into the array of feed material also achieves good heat transfer. This has the potential for achieving a low NO<sub>x</sub> emission.

Rotary kilns continuously stir the material resulting in higher material degradation and consequently a higher particulate emission. The rotary nature of the kiln precludes the possibility of a staged burner device being introduced. The central flame and the lack of convective heat transfer is also likely to lead to higher flame temperatures and consequent higher NO<sub>x</sub> emissions.

Another type of kiln being introduced is fluidized bed technology. The opinion on availability of this technology is divided and therefore it has been treated separately in the following section.

#### *3.4.1.2 Fluidized Bed Technology*

The fluidized bed technology has been undergoing development since the 1960's. The view of the majority is that it needs further development before being fully commercially available. The advantages claimed are that it gives better heat transfer and a long residence time.

The key issue with this technology is that it relies on the control of the bed temperature and the material entering the bed. This is to avoid fusing of the ashes or any other materials which can result in clinker formation. As the temperature is maintained below the melting point of ashes or other materials to avoid clinker formation, the formation of NO<sub>x</sub> is also reduced.

**TABLE 3.7 : SUMMARY OF GENERAL CONTROL TECHNIQUES FOR THE LIME INDUSTRY**

Technique		Pollutant	Advantage	Disadvantage
kiln type	rotary	particulate		higher emissions than other kiln types as material is being turned continuously
		SO <sub>2</sub> , NO <sub>x</sub> , CO <sub>2</sub>		high NO <sub>x</sub> emissions as the flame temperature needs to be high. Higher emissions due to higher fuel consumption per tonne of lime produced - SO <sub>2</sub> from fuel could be significant fraction of total SO <sub>2</sub> emission
	shaft	particulate	lower than for rotary kilns	
		SO <sub>2</sub> , NO <sub>x</sub> , CO <sub>2</sub>	NO <sub>x</sub> emissions lower than for rotary kilns	as above but less fuel used than in rotary kilns
kiln control		SO <sub>2</sub> , NO <sub>x</sub> , CO <sub>2</sub>	improved plant efficiency leads to lower emissions	potential for CO trip in ESP
fuel	gas	SO <sub>2</sub> , NO <sub>x</sub> , CO <sub>2</sub>	low CO <sub>2</sub> , SO <sub>2</sub> production, flexible combustion control	higher fuel usage, high NO <sub>x</sub> production
	oil	SO <sub>2</sub> , NO <sub>x</sub> , CO <sub>2</sub>	flexible combustion control, lower NO <sub>x</sub> emissions than for gas due to lower temperature	higher CO <sub>2</sub> than for gas
	coal	SO <sub>2</sub> , NO <sub>x</sub> , CO <sub>2</sub>	longer burning zone gives better heat transfer from flame	extra energy and local particulate emissions from fuel preparation and handling, high sulphur content can contribute to total SO <sub>2</sub> production for all types of kiln
	pet coke	SO <sub>2</sub> , NO <sub>x</sub> , CO <sub>2</sub>	as for coal	as for coal, other impurities contribute to stack discharge
	SLF	SO <sub>2</sub> , NO <sub>x</sub> , CO <sub>2</sub>	lower NO <sub>x</sub> from stack (demonstrated by trial runs for certain fuel mixtures - new combinations will need their NO <sub>x</sub> reductions similarly demonstrated)	public concern over perceived health hazard

The biggest problem faced by the early fluidized bed designers and users was the generation of large quantities of fine dust; this was produced as a result of the sand and other materials constantly grinding together. Also the limestone, when converted to lime, disintegrates readily and contributes to the dust generation. This fine dust requires sophisticated control to avoid explosion hazard.

On the positive side, the lime dust acts as an effective SO<sub>2</sub> scrubber.

Fluidized beds are capable of taking solids similar to those used in conventional lime kilns. To achieve the thermal efficiency, the gas leaving the bed needs to be cooled by passing it through the feed or some other form of heat exchanger.

To summarize the key issues are of fluidised bed technology are:

- the potential to reduce SO<sub>2</sub>
- the potential to reduce NO<sub>x</sub>
- the potential to increase the dust formation.

#### *3.4.1.3 Improved Kiln Running*

The objective of improved kiln running is fuel efficiency which leads to a reduction in most environmental releases. The techniques available include better burner control, excess air control, and temperature control. All these will have a direct impact on the emissions from the kiln. The low flame temperature when achievable will reduce NO<sub>x</sub> production. Since the temperature required to produce quicklime can be as low as 800°C this is a feasible option.

#### *3.4.1.4 Fuel Selection*

The options for fuel selection in lime kilns are very similar to those for cement kilns with the exception that, due to the smaller kiln sizes, gas is a feasible option for lime processes. The principal fuels that may be used in lime processes are gas, oil, coal, pet-coke and waste derived fuels, in particular Secondary Liquid Fuels (SLF). The main environmental consequence of using different fuels is the effect on releases of SO<sub>2</sub>, with those fuels containing least sulphur (eg, gas) generating negligible SO<sub>2</sub> releases. Fuel choice may also influence releases of particulates and NO<sub>x</sub> but the paucity of monitoring data from the lime sector does not allow any firm conclusions at this time.

#### *3.4.2 Specific Techniques*

Specific techniques for the lime industry are very similar to those for the cement industry and their applicability to lime processes is summarised in Table 3.8. The techniques are reviewed in Appendix C. The key techniques are summarised below.

**TABLE 3.8 : SUMMARY OF SPECIFIC ABATEMENT TECHNIQUES FOR THE LIME INDUSTRY**

Abatement technique	Pollutant	Applicability
ESP -15-20 mm WGap	particulate	best option for particulate control
wet scrubbers		in use mainly with Maerz kilns
cyclone separators		not suitable as final separators
cyclone gravel bed		inherent weakness for lime due to fine particle size
bag filters 150-200 mm WGap		applicable but not suitable as ESPs
coverage dust hoods		suitable for all works
raw material handling covers		
quick lime storage covers		
fugitive leak control		
FGD wet scrubber	SO <sub>2</sub>	not suitable - very high cost
FGD dry scrubber		some processes can be adapted
vortex scrubber		not suitable
selective quarrying		applicable to all works
low S fuel		depends on economic factors
low NO <sub>x</sub> burner	NO <sub>x</sub>	applicable to all kilns
3R Process (NO <sub>x</sub> reduction using fuel)		not proven
NO <sub>x</sub> scrubber using NH <sub>3</sub> injection		claimed to be expensive
SCR (selective catalytic reduction)		claimed to be expensive to be designed for site - not proven
activated charcoal filter		Possible but unproven
POLVITEC process		not suitable for UK industry
Secondary Liquid Fuels (SLF)		Suitable for most kilns - with modification to burners

**Best Available Technique to Reduce Particulate Matter**

There are various options available for dealing with the main process exhaust gases which may include one or more of the following techniques depending upon the type of process and the type of dust to be treated:

- electrostatic precipitators
- fabric filters
- ceramic filters
- gravel bed filters
- cyclones
- wet scrubbers

The best available technique for particulate abatement is considered as an ESP as it has the flexibility of being able to handle large quantities of gases and all types of particulates. Wet scrubbers are used in some Maerz kilns, which produce relatively low levels of releases, this is more due to the kiln design than the abatement technique.

Emissions from the storage, processing, and handling of dusty raw materials and finished products are best contained by enclosure and venting to suitable dust arrestment equipment. Releases from collection hoods should be controlled by locating the hoods as close to emission points as possible. They should also be designed to capture the emission efficiently whilst minimizing exhaust gas volumes. The dust laden gas stream generated should be routed via ducting to control devices (such as filters) where the captured dust is collected and cleaned exhaust gases are vented to atmosphere.

**Best Available Technique to Reduce SO<sub>2</sub>**

Not all the best available techniques for reducing SO<sub>2</sub> available to cement kilns are applicable to lime processes. Feed blending, process efficiency improvements and fuel selection are the best available techniques for SO<sub>2</sub> reduction. Another option considered appropriate is to introduce dry CaO powder or quicklime with the water spray before the ESPs but these techniques are more expensive. Process modification to use CaO to absorb the SO<sub>2</sub> is not possible due to the need to maintain product quality.

**Best Available Technique to Reduce NO<sub>x</sub>**

The best available techniques for controlling NO<sub>x</sub> releases are a combination of combustion control, and low NO<sub>x</sub> burners. Results also indicate a reduction in NO<sub>x</sub> when using SLF, although lime kilns do not lend themselves so easily to burning SLF as cement kilns which operate at higher temperatures. The lower temperature of lime kilns are also more conducive to dioxin formation

### ***Best Available Technique to Reduce Dioxins and Heavy Metals***

Lime kilns are not subjected to heavy metal limits. However the feed and fuel are similar to those of cement kilns. Some lime kilns use natural gas which has a very low of heavy metal content. The lime kilns should be subjected to heavy metal limits similar to those for cement kilns. The best available technique to reduce dioxins and heavy metals is to reduce the particulate emissions as is the case with the cement industry.

### ***Best Available Technique to Reduce CO<sub>2</sub>***

The best available technique for reducing CO<sub>2</sub> emissions is to improve the efficiency of the plant. In addition some kilns use natural gas which inherently produces less CO<sub>2</sub>. The best available technology in use for reducing the CO<sub>2</sub> emissions from lime kilns in the UK is applied at Brunner Mond where the CO<sub>2</sub> is used to produce soda ash.

### ***Control of Pollution from Lime Hydrator***

A common problem with lime hydrators is the very visible water vapour plume. The entrained dust particles act as condensation nuclei thereby causing the plume to be more persistent than would otherwise be the case.

Some plants are fitted with a purpose designed wet scrubber while others are fitted with only cyclones, or irrigated cyclones. The best abatement technique for this process is to design a system with fewer emission points such as welded joints. The second best option is to use local containment so that any potential emission can be contained and abated.

## ***3.5 Economic Assessment of Lime Processes***

### ***3.5.1 Market and Industry Structure***

The production of lime in the UK is carried out both in-house and commercially. In-house production, in which lime is produced for use within the same company, is practised by three main companies: British Steel, British Sugar and Brunner Mond. British Steel produces lime at its main site in the North West to supply its iron and steel smelters across the country, and at a small site in South Wales operated by a joint venture with Wimpey Hobbs to supply the steel works in Llanwern. Together these plants supply around half of British Steel's demand: the remainder is bought in from four principle companies, Singleton Birch, Buxton Lime, Redland Aggregates and ARC. Other steel smelting companies, such as ASW and UES, also buy in lime but in much smaller quantities. The use of lime for iron and steel production accounts for around 50% of the total lime consumed in the UK. British Sugar, owns about 12 small kilns, which produce the lime required in the manufacture of sugar. The total capacity of these kilns is, estimated at around 100,000 tonnes/year. Brunner Mond also produces a substantial amount of lime internally for soda ash production.



The UK commercial lime industry is dominated by a small number of companies : ARC, Buxton Lime Industries, Singleton Birch, Redland Aggregates, RMC and Tilcon. Together these companies account for over 85% of all commercial lime production. Tilcon is now owned by Minorco Minerals, a worldwide mining and mineral processing company which also owns Buxton Lime Industries. The combined output of Tilcon and Buxton Lime Industries makes the group the largest commercial lime producer in the UK.

The uses and end markets for lime are very varied. The principal uses of lime are in the smelting of iron and steel, for building materials (as additives to mortars, and as air entraining agents for concrete products) and for environmental applications. Consumption by these sectors accounts for just under 70% of the UK market (captive and non-captive).

The UK lime industry and external trade position is summarised in Table 3.9. Total output for the sector has fallen by around 14% since 1990, although it has stabilised over the last few years.

### *3.5.2 Ownership and Extent of Activities of Firms*

The majority of lime processes in the UK lime industry are owned by large mining and mineral processing companies, which typically have a range of interests outside the lime sector. Major companies involved in the sector include ARC, Redland Aggregates, Minorco Minerals (through Tilcon and Buxton Lime) and RMC Industrial Materials. These companies which are vertically integrated, owning quarries and facilities to produce lime and a variety of downstream products, such as mortars and other building materials, can have sales figures in excess of £1bn. A few independent operators remain, such as Singleton Birch which have turnovers between £10m and £15m, although these companies also generate a substantial portion of their income from non-lime based activities.

### *3.5.3 Financial Performance of Firms in the Sector*

Information on financial performance of firms in the lime industry has been difficult to obtain and consolidated accounts from the parent companies only provide an indication of the profitability of the lime business. Table 3.10 presents the performance of those companies for which financial data is available and in which lime production accounts for the majority of activities. These data together with confidential anecdotes from the industry are the only sources of information from which the profitability of lime manufacture can be estimated. Bearing in mind these limitations it is estimated that the average (pre-tax, post-interest) profitability of commercial lime production is currently in the range of 5-10% return on turnover, having decreased markedly over the last 5 years. Information on return on capital has not been forthcoming.

TABLE 3.9 : THE UK LIME INDUSTRY

Production	QUANTITY (kt CaO)
Commercial	1,500 <sup>(1)</sup>
In-house	700 <sup>(2)</sup>
Total UK Lime Production	2,200
Imports	9
Exports	45
Total UK Market	2,150
<b>Consumption</b>	
Agricultural	10
Iron and steel	1,300
Chemical use	60
Building materials	240
Sugar manufacturing	100
Environmental	250
Other uses	180
Total	2,150

Source: Business Monitor, 1995, PA1007 (1994 figures); British Lime Association

Notes: 1. Source; British Lime Association  
 2. Includes British Steel and British Sugar. Excludes Brunner Mond.

TABLE 3.10 : FINAL PERFORMANCE OF FIRMS IN THE LIME PRODUCTION SECTOR

	TURNOVER (\$'000)				PROFIT BEFORE TAX (\$'000)				PROFITABILITY			
	1991	1992	1993	1994	1991	1992	1993	1994	1991	1992	1993	1994
Buxton Lime Industries		21,790	44,781			(140)	4,337			-1%	10%	
Singleton Birch		12,690	12,335	4,378		1,887	1,238	2,441		15%	10%	17%
TOTAL	0	34,480	57,116	4,378	0	1,747	5,585	2,441	-	5%	10%	17%

The decline in profitability in recent years is due to two principal factors (i) an introduction of extra capacity into the industry, principally by British Steel, in response to an attempt by commercial producers to raise prices in the late 1980s and (ii) a weakening in demand, particularly in the construction materials sector. The result is now overcapacity in the commercial lime market. Despite these adverse market conditions, however, some firms appear to have made adequate profits during this period.

#### *3.5.4 Capital Vintage*

Since the early 1980s, the lime industry has made significant investments in new process plant, both as a result of environmental compliance measures and to improve production efficiency and reduce costs. Approximately half of the UK's commercial quick-lime capacity has undergone substantial refurbishment over the last 10-15 years.

For the rest of the industry, much of the process equipment dates from the 1950s and 1960s, but has been kept operational by regular investments in new equipment. For these plants, further up-grades or replacement will probably be required in the near future to improve efficiency.

#### *3.5.5 Intra Industry Competition*

With overcapacity in the UK lime industry, competition is becoming more intense. This is evidenced by falling prices of calcined lime products in recent years. Sales and prices reached a peak in 1989, which generated interest from overseas suppliers, in setting up plants in the UK. These plans never materialised though as the subsequent fall in prices made such ventures in the UK economically unviable.

The low price of lime in the UK, together with high transport costs and the limited shelf life (reactivity falls over time) of the product, have reduced imports to negligible levels. Prices of imported lime to coastal steel works, however, can vary considerably from £50/tonne to £400/tonne. Given an increase in UK lime prices, the degree of competition from overseas producers could be expected to increase.

#### *3.5.6 Competition from Substitutes*

The principal alternatives to calcined lime products, the main forms of which are "quicklime" ( $\text{CaO}$ ), hydrated lime ( $\text{Ca(OH)}_2$ ) and burnt dolomite ( $\text{CaO.MgO}$ ), are limestone ( $\text{CaCO}_3$ ), dolomite ( $\text{CaMg(CO}_3)_2$ ) and other alkalis (eg.  $\text{NaOH}$ ). Competition from these products is reviewed for each of the main markets for lime.

### *Iron and Steel*

Iron and steel manufacturing, which accounts for around half of lime consumption in the UK, has traditionally used only calcined lime and burnt dolomite. In the steel making process calcium acts as a desulphurising and fluxing agent, and magnesium, present in the dolomitic form, helps to maintain the integrity of the furnace refractory lining. There is, however, growing interest in substituting lime and some burnt dolomite for the raw material, (calcium carbonate), which is typically less than a quarter of the price of the calcined material. When using the raw material, calcination takes place during the primary stages of the smelting operation. The practice has been developed in the US, and to date has been trialed at one UK steel furnace. The applicability of the technique though is limited by the operating conditions of the individual smelters (relatively low temperatures and high "free space" in the boss are required). Bosses can be readily modified to accept the raw material, but this is a major undertaking requiring an entire rebuild of the boss. Rebuilds usually occur once every 20-25 years and can cost of the order of £100m. Given these and other technical limitations it is estimated that the UK steel industry could convert 20% of its lime usage to limestone, representing a little over 10% of the UK market (captive and commercial) for lime.

### *Building Products and Construction*

Three main types of products are made in the building products and construction sector, lime/cement mortars, aerated concrete products and fire resistant boards. Lime competes with cement and chemical admixtures (used as air entraining agents) in the production of lime/cement mortars, and other calcium containing compounds (such as cement, pulverised fly ash, or blast furnace slag) in the manufacture of aerated concrete products and fire resistant boards. The use of these materials has increased in recent years reducing the market share of lime. It should be noted though that the production of cement is also a regulated process under the same IPC sector as lime, and pressures to pass on additional costs from expenditure on pollution control will affect the prices of both products.

### *Environmental Uses*

For environmental applications, lime competes with sodium hydroxide, calcium carbonate, and other "waste" alkalis derived from a variety of sources. This tends to be a more price sensitive market than other sectors with consumers able to switch relatively easily between products.

### *Other Uses*

In the chemicals market, lime has a number of technical advantages over alternatives, and comparatively little substitution is possible. In water treatment applications lime principally competes with sodium hydroxide but the choice of material is influenced as much by technical

characteristics as price, and the price sensitivity of demand is perhaps less than in other markets, such as building products.

In summary, lime competes directly with the uncalcined, raw material and alternative products in a number of markets, and in some cases these are gaining market share. The sensitivity of lime demand to changes in prices, however, depends very much on the particular application.

#### *3.5.7 Cost of Techniques to Control Releases*

Environmental releases from lime processes and the techniques employed for their control are similar to those proposed for cement processes. Table 3.11 shows the delivered costs (excluding ducting and civil work) of the main pollution control techniques applicable to lime processes, presented in terms of actual costs and cost per tonne of lime produced. Owing to the small size of a typical lime plant compared to a cement process (100 tpd for lime compared to 2,000 tpd for cement), control costs are, in nominal terms, generally lower than at a typical cement works, although unit costs are higher. For certain control techniques, however, cost is more closely related to the nature of the process than plant size. In particular, the fine dust size of lime materials substantially increases the costs of dust controls in materials handling measures, and SNCR costs are higher than cement processes as a result of the lower kiln operating temperatures.

#### *3.5.8 Economic Implications of Additional Pollution Control Costs*

The principal releases of concern in the lime industry are those to air. From a review of HMIP authorisations it is possible to show the extent to which existing lime processes are fitted with air pollution control devices. This is shown in Table 3.12.

Owing to the limited use of air pollution control techniques, the costs of installing new equipment or upgrading existing processes to reduce releases for the industry as a whole are likely to be significant. The profitability of lime production is not known with any degree of certainty, although firms appear to have made adequate profits, even in a depressed market, with sustained levels of capital investment. With some industry re-structuring now taking place, average profitability should improve.

**TABLE 3.11 : COSTS OF TECHNIQUES TO CONTROL RELEASES FROM LIME MANUFACTURING PROCESSES**

Technique	Capital cost (\$ million)	Operating cost (\$'000)	Annualised cost (\$'000)	Cost per tonne (\$)
ESP Replacement	1 - 3	20	180 - 500	5.0 - 14
Bag Filter Replacement	2 - 4	600	930 - 1,250	26 - 36
ESP/Bag Filter Up- grade	0.5 - 0.9	20	100 - 170	3.0 - 5.0
Materials Handling Measures	4 - 6	-	650 - 980	19 - 28
Selective Quarrying	0.2	80	110	3.0
Lime addition	0.8	30	160	5.0
FGD (dry)	3 - 6	400	890 - 1,380	25 - 39
FGD (wet)	6 - 8	400	1,380 - 1,700	39 - 48
Fuel Selection (low sulphur coal - 1% content compared to a usual 1.4%)		30 - 60	30 - 60	0.8 - 1.6
Combustion Control	0.7	-	110	3.0
Staged combustion	0.8	350	480	14
SNCR	3 - 4	250	740 - 900	21 - 26

**TABLE 3.12 : POLLUTION ABATEMENT IN THE LIME INDUSTRY**

ABATEMENT TECHNIQUE	PROPORTION OF INDUSTRY CAPACITY
Cyclones	1 - 2%
Wet Scrubbers	~15%
ESPs	~ 40%
No Particulate Abatement	~ 43%
Acid Gas Treatment	none

Substitutes to lime are prevalent and provide competition in a number of lime markets. Due to the low price of lime in the UK, imports are not significant at present, but should prices rise significantly, the potential threat from imports will increase. Consequently, opportunities for passing on costs to customers are limited to certain niche markets, such as chemicals and, to some extent, water treatment.

In-house lime production principally contributes to the manufacture of three commodity products; steel, sugar products and soda-ash. These products are traded internationally and markets are very price sensitive. There is thus little opportunity for these lime producers to pass on additional costs to customers.

In general though it is considered that all lime producers, should be able to afford improvements in their overall environmental performance. In particular, the costs of up-grading older plants to BAT standards for particulate control are not considered excessive. For these plants, particulate releases may be reduced by replacing or up-grading an ESP or bag filter, at a typical cost of £3 - 5 and £5 - 14/tonne respectively. Improving materials handling measures, is more costly, of the order of £19 - £28/tonne.

At those plants (old and new) where releases of SO<sub>2</sub> and NO<sub>x</sub> are high, controls could be implemented at approximate costs of £5/tonne (lime addition) and £3/tonne (combustion controls) respectively. Where such measures are the only new control measures required then the costs should be within the financial means of the plant. Where particulate controls are also required the additional costs of NO<sub>x</sub> and SO<sub>x</sub> controls may be excessive, although site specific environmental factors will determine whether they are required at a particular plant.



## 4 SUMMARY AND CONCLUSIONS

### 4.1 Key Technical Issues

Recent and current data have been collected on the technology of the industry sectors; this was then assessed in order to identify and categorize the environmental impacts of these sectors. This included impacts on air, water, and land.

This study has reviewed the manufacture of both cement and lime in order to establish:

- i) the pollutants emitted from the process,
- ii) the environmental impact of the pollutants released,
- iii) the abatement techniques available.

Both the cement and lime industries use limestone as feed material and heat it in a kiln producing  $\text{CO}_2$ . They are both capital intensive processes. The secondary processes associated with preparation of the feed and the treatment of the product are inherently dusty and generate large quantities of particulate. The materials emitted through the stack are similar for cement and lime processes, producing  $\text{CO}_2$ ,  $\text{SO}_2$ ,  $\text{NO}_x$ , and particulates, and small quantities of dioxins.

The principal difference in the two processes is that lime ( $\text{CaO}$ ) is produced by simply heating limestone ( $\text{CaCO}_3$ ) whereas cement manufacture takes the process further to produce clinker which is then ground to form cement. The major differences with respect to nature of the process and the environmental impacts were found to be:

- i) Cement manufacture involving clinkerisation and calcination whereas lime production only involves calcination.
- ii) Cement manufacture requires maintaining a high temperature ( $1400\text{--}1500^\circ\text{C}$ ) compared to that for lime production ( $800^\circ\text{C}$ ). Consequently cement manufacture has the potential to produce more  $\text{NO}_x$ .
- iii) The two stage process of cement production allows most  $\text{SO}_2$  produced from the fuel to be absorbed in the clinker. Some  $\text{SO}_2$  absorption also occurs in the pre-heater sections of lime kilns, but to a lesser extent.
- iv) Dust produced from the lime industry is lighter and therefore tends to be carried to greater distances compared with dust from cement manufacture.
- v) The high temperatures associated with cement manufacture make it suitable for burning SLF (Secondary Liquid Fuel).

For both cement and lime processes the key issue was the separation of the emissions and the environmental impacts into the near field, far field, and global domains as opposed to considering only the stack emissions. For both industries the near field impacts were found to be more significant than the far field and global impacts.

A number of techniques to reduce the emissions by eliminating, minimizing, or rendering harmless have been identified; these are profiled in Appendices B and C for cement and lime processes respectively.

For both industries, it was found that the most effective general control approach was to improve process control and the performance of the existing abatement equipment. The flue gas desulphurization and NO<sub>x</sub> reduction by NH<sub>3</sub> injection and carbon filter bed were also considered, but they were found not to be as suitable.

Significant near field environmental improvement was found to be achievable by reducing fugitive emissions of dust. The BAT for doing this is the rigorous application of standard dust control measures and general good housekeeping.

The other major conclusions were:

- SO<sub>2</sub> reduction is achievable by selective quarrying and - where applicable - recirculating some of the calcined material with the feed for the cement process, and some lime with the feed for the lime process.
- NO<sub>x</sub> reduction is possible by adopting the dry process (for cement processes) or by process modification (cement and lime processes) to avoid high temperatures and excess air. For dry cement processes with pre-calcination the concept of the 3R Process can be applied.
- Heavy metal and dioxins are best reduced by controlling the dust emission (cement and lime processes) and maintaining a low ESP temperature to reduce dioxin reformation (cement processing).

#### **4.2 Key Commercial Issues**

Whilst cement and lime processes use similar production technology and require similar abatement techniques, the differences in the nature of the two products, their markets and industry structures, means that the implications of moving towards the best available techniques for the two industries require separate consideration.

The UK cement industry operates in a highly competitive international market, and this has a major impact on the ability of firms to afford new pollution control systems. Domestic UK prices are effectively capped by the prices of imports. Given this restriction, the ability of the UK companies to afford additional pollution control costs is limited to the reduction in return on capital that the companies concerned can sustain without significantly affecting investment decisions. This is estimated at a total net cost of around £0.5 m/tonne of cement produced. Further costs should also be able to be afforded up to £0.5/tonne, as process and distribution efficiency improves.

The lime industry operates in a very different market. Competition is derived more from substitute products, however, than threats from imports. Consequently the opportunity for lime producers to pass on additional costs is on the whole limited, although some niche sectors, such as chemicals manufacture, are less exposed to pressures from substitutes and it may be possible to pass on some of the additional cost in these applications. Overall it is considered that all lime producers should be able to afford to up-grade emission controls to BAT standards for particulates. Where measures to control SO<sub>2</sub> and NO<sub>x</sub> are the principal control techniques, then these should also be within the financial means of the plant.



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**APPENDICES A.1 - A.5**

**ENVIRONMENTAL IMPACTS OF CEMENT AND LIME PROCESSES**



## **APPENDIX A.1 : ENVIRONMENTAL IMPACTS OF CEMENT AND LIME PROCESSES**

The environmental impact of cement and lime processes are reviewed according to their impacts on the near field, far-field and global environments.

### **1. Near Field**

The principal near field impacts are: noise, visual, and those due to particulate emissions, liquid waste, solid waste, and gaseous emissions. These impacts are summarised in Appendix A.2.

#### **Noise**

The noise pollution comes from a number of sources:

- quarry blasting
- heavy machinery
- industrial motors and fans including abatement equipment
- transport systems

Noise is known to have a high impact on the local population because there have been a number of recorded complaints (at both cement and lime processes).

#### **Visual**

The visual impacts associated with cement manufacturing arise from the large physical size of the chimneys and calciners (vertical kilns, in the case of lime processes), the dust and steam plumes emanating from the works. The presence of steam in the plume enhances its visibility and therefore exacerbates its visual impact - most of the complaints received concerning the visibility of the plume are related to plume grounding or dust emissions (only for cement processes).

#### **Particulate Emissions**

The impact of particulate emissions on the near field is high for both cement and lime production. Vegetation can be covered by a coating of dust. The dust generally comes from feed preparation and is therefore pH neutral. However, a small proportion of clinker and cement dust; and a high proportion of lime dust, emitted is alkaline; this can have a potentially detrimental effect on flora and fauna. There is some anecdotal evidence that workers employed in the lime industry worldwide over the last 50 years have suffered from respiratory problems as a result of high dust concentrations. In the UK cement industry, health and safety precautions have eliminated such health effects. However, the levels of local particulate emissions are still significant from an environmental point of view and controlling these emissions may be more important than controlling emissions through the stack.

## **Liquid Waste**

Liquid wastes from cement and lime works is minimal. However, the controlled water discharge for the entire works including the quarry is high.

Water collected in the quarry has to be pumped out. The quality of such water is monitored and the discharge is agreed with the appropriate regulators - mainly the NRA.

Other sources of water discharge from the site are: the rain-water surface run off; the actual water discharge from the site; the filtrate from the semi-wet process; and the cooling water from a number of small operations. These are collected and monitored. The only other forms of liquid discharge are potentially, the lubricant and other oils used on site. There is no routine discharge of such liquids. The fugitive discharge of this liquid is minimal as the performance of the machinery is monitored. Any significant releases will be accidental. If such releases occur they will be small; furthermore the operation and maintenance of the sites generally ensures that any accidental release are identified and dealt with promptly.

In the case of lime processes, although the slaking procedure involves the use of significant quantities of water, most of this is recycled.

## **Solid Waste**

The main form of solid waste from the cement manufacturing processes is the collected cement kiln dust (CKD). To meet the requirements for low alkaline cement, this dust is not recycled into the process. The CKD is taken to a purpose-designed and controlled land fill; as such the long term environmental impact is not significant. The short term impact is however important; this is the impact due to transportation of the solid waste and the associated noise and fugitive dust emissions.

Quantities of collected dusts from lime works, that cannot be re-used in the process are relatively small.

## **Gaseous Emissions**

The near field impact from gases is mainly that from fugitive gas emission from the process. Other sources such as coal or oil fired space heaters and fuel heaters for coal or heavy fuel oil (lime processes) fired installation also need to be considered. There may also be some methane released from coal stock piles on site. This is particularly significant for cement processes which require larger stocks of coal than lime processes.

## **2 Far Field**

The principal impacts in the far field are visual and those due to particulate and gaseous emissions. The full impacts are summarised in Appendix A.3.

## Visual

The visual impact in the far field is minimal. It is limited to the chimney and any visible plumes. The impact of the latter is insignificant for dry cement processes and those cement without any wet scrubbing. The introduction of wet scrubbing for both cement and lime processes, however, may create a far field visual impact. This type of pollution is a key issue in the waste incineration industry where there are requirements by HMIP to heat the exit gases from the scrubbers to a temperature sufficient for the plume not to be visible.

## Particulate Emissions

Emissions from the stack can lead to the far field deposition of particulates. For new cement and lime plants the emission standard is limited to a maximum of 50 mg/Nm<sup>3</sup>, although higher levels have been authorized for existing current plant. The 50 mg/Nm<sup>3</sup> level gives rise to very low ground level concentrations. The key issue should be the ability of the environment to recover from such low level ground concentrations. The ground level concentrations resulting from any fall out from a normal cement or lime works chimney are likely to be low compared to dust created locally by normal activities.

Most of the particulate emissions are:

- limestone
- calcium oxide
- some clinker material (fine CKD) - in the case of cement processes.

The dusts in general are alkaline whereas the gaseous emissions are acidic. Once the particulates have settled on the ground by rain or natural fall-out the potential exists for neutralization by the acidity of the stack gases. The result is not necessarily neutral though: it is likely to be acidic rather than alkaline, as the acidity of the stack gases is likely to exceed the alkalinity of the dust.

Trace quantities of heavy metals and dioxins are also carried over with the particulate. Although significant intake of any such heavy metal will have adverse health impacts on animals or humans, the contribution of these pollutants is likely to be negligible in comparison with that from the background level due to the small quantities involved.

## Gaseous Emissions

Far field gas pollutants from any cement manufacturing site are:

- SO<sub>2</sub>
- NO<sub>x</sub>
- NH<sub>3</sub>
- CO<sub>2</sub>

These pollutants can have both far field and global impacts. The main far field effects occur when conditions prevent effective plume dispersion, e.g. adverse wind conditions or formation of inversion layers. The acidic gases in general can affect vegetation and aquatic life as the pH concentration of the water may change.

### **3 Global**

The main global pollutant from cement works is CO<sub>2</sub>. However SO<sub>2</sub> and NO<sub>x</sub> may also have some impact. These effects are assessed in Appendix A4.

Production of large quantities of CO<sub>2</sub> is an inevitable consequence of the chemical reactions and the burning of fuel in the cement and lime manufacturing processes. The most significant global environmental impact is the contribution of these gases to global warming.

#### **Assessment of Environmental Impacts of Cement and Lime Processes**

The environmental impact assessment of cement (and lime) processes) needs to be holistic - that is to consider both negative and positive factors and to evaluate the relative contributions from a variety of sources, pathways and effects. There are a number of standard impact assessment formats available. Most of these are in a generic format applicable to most industries. The list for this study is from that proposed for Environmental Impact Assessments in the 1985 EC Directive and the 1988 Town and Country Planning Act<sup>3</sup> and adapted to suit for cement and lime industry.

To be consistent with the rest of the study the environmental impact are assessed in three domains - near field, far field, and global.

In each domain the impacts are assessed by considering for each pollutant the:

- potential to pollute
- actual pollution
- control or abatement techniques available
- priority that should be given to control the emission.

The above is mapped against the potential to have impacts on the following aspects of the environment:

- air quality
- water resources
- noise
- flora and fauna
- human environment and health
- land use
- historical, cultural, and recreational resources
- society and the economy.

## **APPENDIX A.2 : ASSESSMENT OF ENVIRONMENTAL IMPACTS OF CEMENT AND LIME PROCESSES**

### **1. Near Field**

The assessment environmental impacts for the near field are summarized in Append A.3. The basis for the high/medium/low assignments in each category is now provided.

Near field gaseous and particulate emissions have the potential to affect atmospheric quality. The only sources of near-field gaseous emissions are fugitive emissions and these are very low. Particulate emissions are more problematic and can have a significant effect on the near field environment. These emissions are mainly fugitive and come from a number of sources. The following have been considered in compiling Appendix A.3.

- The release from a typical site
- Available techniques and management procedures available to control such emissions
- Priority to be given to reduce the overall impact on the environment.

#### **Impact on Air Quality from Gases**

- **Potential Impact**  
The potential for gaseous releases that could have a near field environmental impact arise mainly from fugitive emissions. Releases may also occur during gas by-pass operations required as part of the process; however this is required for only short periods and therefore the potential is low.
- **Actual Impact**  
The actual cannot be greater than the potential and so is low.
- **Control available**  
Control is by careful design of the plant - which is generally under negative pressure - to reduce fugitive emissions. Most of the fugitive leaks are due to vibration of machinery and rotating plant items. The levels of vibration can be minimized by appropriate design and maintenance which also has a concomitant economic benefit through reduced plant wear.

#### **Impact on Air Quality from Particulates**

- **Potential Impact**  
The emission of particulate from cement works is normally high. There are a number of sources which are classed as fugitive and often result from poor housekeeping. The slaking process at some lime manufacturing plants is a particularly significant source of particulates from those processes.

- **Actual impact**  
The impact in general was found to be high from both cement and lime processes. The local vegetation is normally covered by a layer of dust. The industries also accept they need to improve their housekeeping and local fugitive emission control.
- **Control available**  
The control techniques available are technically simple and require good housekeeping and containment. Finer materials are being handled in the food and pharmaceutical industries without any noticeable discharges. There is potential to reduce the emissions although it may not be necessary or practical to reach the standards of the food and pharmaceutical industries.
- **Priority**  
Considering the environmental impact and the relatively simple control techniques available, this is considered to be high priority.

### **Impact on Water Resources**

- **Water - Chemical pollution**
  - **Potential Impact**  
Potential to impact on the water environment from process operations is low as all the process water is contained. Good practice is to analyse and treat before supply, therefore the potential is very low. Actual contaminations, therefore tend to be low. The potential for the release of surface - water run-off containing alkaline materials, however, may be significant and should be reviewed at each site.
- **Water - Thermal Potential**  
Cement and lime works do not use any significant amount of cooling water and so thermal pollution is minimal.

### **Noise**

The potential for noise pollution in the near field is high due to the number of machines. However the normal noise abatement installed makes the actual noise level low.

### **Impact on Vegetation and Wildlife**

The initial impact and wildlife on vegetation is during the quarrying and operation of cement and lime processes. These are not considered significant given the other impacts of these processes. Once the mining is finished however the quarrying is either restored or used for an alternative purpose, principally the landfill of wastes. Landfill has its own environmental impacts but these are not within the scope of this report.

### **Impact on Human Environment and Health**

- **Potential**  
Impact on the human environment and health from cement and lime processes is high mainly due to near field particulate emissions.
- **Actual**  
Since most of the environmental improvements sought and achieved were directed towards reducing stack emissions, no significant reduction in fugitive emissions in the near field have generally been made.
- **Control available**  
There are a number of well established cost effective techniques available to reduce the fugitive emissions to the near field.

### **Impact on Land Use**

The impact on land use is similar to that of the impact on vegetation and wildlife. The negative effects are normally well controlled. Therefore even though the potential for impact is high the actual impact is low; hence the priority is also low.

### **Impact on Historical, Culture, and Recreational Resources**

This is mainly site specific. For the UK cement and lime industries this is low with respect to near field.

### **Socio-Economic Impact**

This is considered under the headings:

- product
- employment
- people

Although the product has a high positive net benefit it has low positive contribution in the near field.

The highest net positive contribution to the near field is the employment, both direct and indirect. In most cases there is a substantial local economy dependent on the cement industry, for both direct and indirect employment.

## 2 Far Field

The environmental impacts for the far field are summarized in Appendix A.4. The basis for the high/medium/low assignments in each category is given below

The main contribution to the far field environmental impact is from the emissions from the stack, viz.: gases ( $\text{SO}_2$ ,  $\text{NO}_x$ ) and particulates.

### Impact on Air Quality from Gases

- Potential

The potential for any gas emissions from a cement or lime works is medium. This is because the quantities of acid gases released are low compared with that from power stations although in welcoming the total mass emission of these pollutants, all releases must be addressed. Whilst the calculated and measured ground level concentrations are low and are typically below the environmental action level, gaseous emissions of  $\text{SO}_2$  and  $\text{NO}_x$  are some of the most significant releases from cement processes.

- Actual

In most cases the ground level concentrations are reduced through dispersion and are below action levels. Control available is limited mainly to process control. Abatement techniques although available can be costly.

- Priority

The priority is ranked medium.

### Impact on Air Quality from Routine Particulate Discharges

- Potential impact

Since the processes are inherently dusty the potential to pollute the far field is also high.

- Actual Impact

All current kilns in the UK are fitted with ESP which reduces dust emissions to levels ranging between  $20 \text{ mg/Nm}^3$  and  $80 \text{ mg/Nm}^3$ . Even at emissions on the higher end of this range, for field ground level concentrations are unlikely to cause significant. Therefore the actual for field impact when the nature of the particulate and the ground level concentration is considered is ranked low. Only a few lime kilns are fitted with ESPs which results in higher emissions, although for field ground level concentrations are still unlikely to be receded.

- Control Available

Although there are a number of technologies available for abatement techniques the one most suitable for with the cement and lime industries is ESP. It has the potential to improve its dust collection by making flow distribution improvements, introducing additional banks of elements, or automated voltage control, or a combination of these.



- **Priority**

Although far field particulate deposition (from cement processes) particulate matter released from lime processes is a final size and has the potential to carry further. Overall far-field particulate impacts are given a medium priority.

### **Impact on Water Resources**

The ranking for most are low; this is based on the arguments for the near field.

### **Noise**

Insignificant.

### **Impact on Vegetation and Wildlife**

Effects are less significant than for the near field. Particularly when the ground level concentrations of the pollutants are below the environmental action level.

### **Impact on Human and Health**

Effects are less significant than for the near field. Particularly when the ground level concentrations of the pollutants are below the environmental action level.

### **Impact on Land Use**

Environmental impact on land use is generally low for the far field as most of the quarries and land fills are in the near field.

### **Impact on Historical, Cultural, and Recreational Resources**

The effects are similar to those for the near field.

### **Visual Impact**

- **Potential**

The potential visual impacts are the chimney and any visible plume. Therefore the potential impact is low. However the quarry could leave a big scar with a high impact

- **Actual**

Most plumes are dry and hot enough to avoid visibility being a problem.

- **Control Available**

Controllability is high as the exhaust gases can be heated to reduce visibility. Redundant quarry restoration techniques mean a low residual impact can be achieved.

## **Socio-Economic Impact**

- **Product**

Although the positive impact of the product is high on a global basis, when considering far field it has to be ranked a medium or low, with the rest of the categories resulting in a medium to low ranking.

- **Employment**

The potential and actual impacts and the ability to control the impacts need to be considered together. When both direct and indirect impact are considered it should be ranked at best medium. The priority is ranked high when the number of people and other industries linked directly or indirectly is considered in addition.

## **3 Global**

The global impacts from cement and lime processes are summarized in Appendix A.5 and are principally:

- impact on human environment and health
- socio-economic impact.

The impact on human environment and health is mainly due to the CO<sub>2</sub> emission and the resulting contribution to global warming. The only feasible ways to reduce CO<sub>2</sub> are to improve fuel efficiency and the use of lower carbon fuel such as natural gas or liquid figures.

The product has a high positive impact on society as a whole.

**APPENDIX A.3 : SUMMARY OF NEAR FIELD ENVIRONMENTAL IMPACTS FOR CEMENT AND LIME PROCESSES**

(all impacts are negative when otherwise stated)

		Potential	Actual	Control available	Priority
Impact on air quality	gaseous emissions	Low	Low	Low	Low
	Particulate	High	High	High	High
Impact on water resources	Process disadvantages	Low	Low	Low	Low
	cooling water - thermal pollution	Low	Low	Low	Low
	surface run-off	High	Low	High	High
noise		Medium	Low	High	Low
Impact on vegetation and wildlife		Medium	Low	High	High
Impact on human environment and health		High	High	High	High
Impact on land-use		High	Low	High	Low
Impact on historical, cultural and recreational resources		Low	Low	Low	Low
socio-economic impact	product	Low(+ve)	Low(+ve)	Low (+ve)	Low (+ve)
	employment/economy	High(+ve)	High(+ve)	High(+ve)	High(+ve)

**APPENDIX A.4 : SUMMARY OF FAR FIELD ENVIRONMENTAL IMPACT FOR CEMENT AND LIME PROCESSES**

(all impacts are negative unless otherwise stated)

		Potential	Actual	Control available	Priority
Impact on air quality	gaseous emissions	Medium	Low	Medium	Medium
	Particulate	High	Low	High	Low
Impact on water resources	Process discharge	Low			
	cooling water - thermal pollution	Low			
	Surface run-off	Low	Low	Low	Low
noise		N/A	N/A	N/A	N/A
Impact on vegetation and wildlife		Low	Low	Low	Low
Impact on human environment and health		Low	Low	Medium	Low
Impact on land-use		Low	Low	Low	Low
Impact on historical, cultural and recreational resources		Low	Low	Low	Low
Impact visual		Low	Low	High	Low
socio-economic impact	product	Medium(tve)	Medium(tve)	Medium(tve)	Medium(tve)
	employment/economy	Medium(tve)	Medium(tve)	Medium(tve)	High(tve)

**APPENDIX A.5 : SUMMARY OF GLOBAL ENVIRONMENTAL IMPACTS FOR CEMENT AND LIME PROCESSES**

(all impacts are negative unless otherwise stated)

		Potential	Actual	Control available	Priority
Impact on air quality	gaseous emissions	Low	Low	Low	Low
	Particulate	Low	Low	Low	Low
Impact on water resources	Process discharges	Low	Low	Low	Low
	cooling water - thermal pollution	Low	Low	Low	Low
	Surface run-off	Low	Low	Low	Low
noise		Low	Low	Low	Low
Impact on vegetation and wildlife		Low	Low	Low	Medium
Impact on human environment and health		High	Medium	Low	High
Impact on land-use		Low	Low	Low	Low
Impact on historical, cultural and recreational resources		Low	Low	Low	Low
Impact visual		Low	Low	Low	Low
socio-economic impact	product	High(+ve)	High(+ve)	High(+ve)	High(+ve)
	employment/economy	Low(+ve)	Low(+ve)	Low(+ve)	Low(+ve)

**APPENDICES B.1 - B.6**

**APPENDIX B.1 : SUMMARY OF UK CEMENT CLINKER PRODUCTION**

Company	Plant	Process	Capacity (te/day)
Blue Circle	Cauldon	dry (pre-calciner)	2800
	Dunbar	dry (pre-calciner)	3000
	Aberthaw	dry	1700
	Hope	dry	1900
		dry	1900
	Weardale	semi-dry	1050
		semi-dry	1050
	Northfleet	semi-wet	1800
		semi-wet	1800
	Masons	wet	1150
	Cookstown	semi-dry	1150
	Pymstock	dry	1000
	Westbury	wet	950
		wet	950
Rugby	South Ferriby	semi-dry	1100
		semi-dry	1100
	Rochester	semi-wet	2200
	Southam	semi-wet	600
		semi-wet	650
	Barrington	wet	770
	Chinnor	wet	220
		wet	260
		wet	260
	Rugby	wet	1000
Castle	Ketton	dry	1060
		dry (pre-calciner)	3100
	Ribblesdale	wet	1000
		wet	1070
		dry (pre-calciner)	2500
	Padeswood	dry (long kiln)	840
		wet	420
		wet	420

**APPENDIX B.2 : SUMMARY OF RELEASES FROM CEMENT PROCESSES**

Process Stage	Released Substance					
	Particulate Matter	Acid Gases		Heavy Metals	Dioxins	Others
		NOx	SO <sub>2</sub>			
raw material handling and preparation	A					
crusher	A					
raw material storage	A					
raw milling	A					
fuel preparation (coal milling)	A	A	A			CO <sub>2</sub>
gas transport (pump costs + leakage)						CO <sub>2</sub> and methane
pre-heater	A	A	A	A	A	CO <sub>2</sub>
kiln	A	A	A	A	A	CO <sub>2</sub>
clinker storage	A/W					
cement milling	A					
cement storage	A					
packaging and dispatch	I					
air pollution abatement plant	I					w

Key:            prescribed substances emission to:        Air (A), Water (W), Land (L)  
                   other substances emission to:        air (a), water (w), land (l)



**APPENDIX B.3 : OPTIONS FOR CONTROLLING RELEASES FROM CEMENT PROCESSES - RAW MATERIALS**

Pollutant	Eliminate	Minimize	Render Harmless
SO <sub>2</sub>	select quarry whenever possible	<p>consider blending with low S feed</p> <p>low SO<sub>2</sub> process, such as pre-calciner</p> <p>consider introducing calciner material before precipitators</p> <p>FGD</p> <p>process modification: introduce dry process module to wet process also convert wet to dry process</p> <p>vortex scrubbers</p> <p>high temperature</p> <p>heat exchanger redesign</p>	<p>high chimney and high</p> <p>gas exit temperature to ensure dispersion</p>
NH <sub>3</sub>	select quarry whenever possible	consider blending material from other sites	<p>high chimney and high gas exit temperature</p>
VOC, TOC	select, screen, or blend if possible	afterburn, use afterburner at exit of process	high chimney and high gas temperature
particulate and heavy metal	<p>process selection</p> <p>grind coarse</p> <p>penalty is poor heat transfer and high gas temperature resulting in low efficiency and more NOx, SO<sub>2</sub>, CO<sub>2</sub></p>	<p>abatement eg:</p> <p>ESP</p> <p>bag filters etc</p>	<p>high chimney and high gas temperature</p>

# **APPENDIX B.4 : OPTIONS FOR CONTROLLING RELEASES FROM CEMENT PROCESSES FUELS**

Pollutant	Eliminate	Minimize	Render Harmless
particulate	<p>use gas and liquid fuel with low ash will have some perceived reduction however ash in fuel has no effect as it is mostly incorporated into the matrix of the clinker during the process</p> <p>use SF or gas to replace coal the use of coal requires separate air heater which is a small source of particles</p>	<p>use abatement equipment for coal fired heaters</p>	<p>high chimney and high gas temperature for good dispersion</p>
CO <sub>2</sub>	<p>use low carbon fuel</p> <p>natural gas</p> <p>SF</p> <p>Increase plant efficiency</p> <p>select low CO<sub>2</sub> process such as dry</p> <p>low exit temperatures. Improve plant efficiency</p>	<p>there are a number of CO<sub>2</sub> abatement techniques available but none is considered to be environmentally efficient</p>	<p>high chimney and high gas temperature for good dispersion</p>
SO <sub>2</sub>	<p>S in fuel has no significant effect on the SO<sub>2</sub> emission</p> <p>elimination of SO<sub>2</sub> is from the use of fuel with no pre-heat requirement, ie SF, gas, oil</p> <p>coal requires heating/milling</p>	<p>improve plant efficiency to reduce pre-heat requirement</p> <p>fuel has no significant effect on the SO<sub>2</sub> emission, as the preheaters acts as dry scrubbers</p>	<p>high chimney and high gas temperature for good dispersion</p>

**APPENDIX B.4 : CONTINUED....**

Pollutant	Eliminate	Minimize	Render Harmless
NOx	<p>use low nitrogen fuel in calciner</p> <p>combustion control: excess air fuel properties (natural gas, some SF) fuel preparation eg fine grinding</p> <p>feed preparation</p> <p>low NOx burner</p> <p>fuel efficiency</p> <p>process modification Introduce 3R concept by Introducing stages calciner</p>	<p>NH<sub>3</sub> Injection</p> <p>carbon filter</p> <p>scrubber</p> <p>POLVITEC process</p>	<p>high chimney and high gas temperature for good dispersion</p>
heavy metals	<p>use fuel with low heavy metal content for volatile metals It will have some effect, but It has no effect for refractory metals as they will be captured in the clinker</p>	<p>select suitable process abatement ESP and others applicable to particulate</p>	<p>high chimney and high gas temperature for good dispersion</p>
dioxins	<p>eliminate Cl in fuel</p> <p>maintain appropriate temperature throughout the process</p> <p>particularly to maintain low temperature in the ESPs</p>	<p>carbon filter</p> <p>abatement</p>	<p>high chimney and high gas temperature for good dispersion</p>

**APPENDIX B.5 : SUMMARY OF APPLICABILITY, ADVANTAGES, DISADVANTAGES, AND NET BENEFIT OF CONTROL TECHNIQUES FOR EACH POLLUTANT**

Pollutant	Method	Applicability	Advantages	Disadvantages	Net Benefit
SO <sub>2</sub> from feed	<i>Eliminate</i> select quarry	mainly for new quarries - key is to consider this at the beginning	real environmental benefit and reduction in SO <sub>2</sub>	not always possible	real reduction in SO <sub>2</sub> if achievable
	<i>Minimize</i> blending low S feed	It may not be available - consider total survey of the quarry and plan quarrying for blending	no real reduction of SO <sub>2</sub> release to the environment over the lifetime of the quarry but averaging of SO <sub>2</sub> emission over lifetime allows environmental recovery  reduces need for abatement - abatement can transfer environmental damage elsewhere  facilitates compliance with limits by giving lower average concentrations emitted	no real disadvantage for the environment but manufacturers may have to have a long term strategic plan  also cost of ground survey	helps to achieve low ground and stack concentrations may reduce the need for abatement  averaging dose will allow the environment to recover more easily
	use low SO <sub>2</sub> process such as pre-calciner and consider calciner material before precipitator and recover through cyclone	It is claimed by F L Smidth that such processes are practical  It is also claimed by FL Smidth that wet process can also be retro-fitted to achieve this	real reduction in SO <sub>2</sub> as the sulphur will be captured in the clinker	energy loss through transfer of material from one end of kiln to the other end  Introduces possibility of fugitive emissions during handling	benefits are site- specific and so careful examination on a site-specific basis

Pollutant	Method	Applicability	Advantages	Disadvantages	Net Benefit
SO <sub>2</sub> from feed	heat exchanger redesign counter to parallel flow	good concept but not applicable due to size and pressure drop characteristics outweighing benefits			
	high temperature	not yet fully understood - further data collection and interpretation of results is needed	may reduce SO <sub>2</sub> at the expense of increasing NO <sub>x</sub> production	increase in NO <sub>x</sub> production product quality will suffer	no real benefit can be deduced from the data available so far - further trials are required more likely to be detrimental as a result of NO <sub>x</sub> production
	FGD flue gas desulphurization unit	applicable to most kilns at a very high capital expenditure	will reduce the stack concentrations	lower gas exit temperatures will result in higher CO <sub>2</sub> ground level concentrations and possible higher level concentrations of other gases visual impact	perceived benefit low SO <sub>2</sub> emission from the stack no overall benefit to the global environment is likely, particularly when the operating energy cost and the associated CO <sub>2</sub> and other pollutants are considered
	vortex scrubber	not applicable to cement industry			
	render harmless high chimney	applicable to new installation. may be possible to extend some chimneys	reduced ground level concentration slight reduction in operating power due to stack effect	visual impact diminishing return on investment	real reduction in ground level concentration and real reduction in power consumption
	high gas exit temperature	applicable to both new and existing plant	good dispersion hence low ground level concentration	inefficient cement production increase in fuel usage hence increased emissions	negative real benefit as more fuel is used
	air dilution	all sites	low ground level and stack concentrations low CO trip from ESP	increased energy use low stack exit temperature leading to poorer dispersion	In general no net benefit but worth considering for interim air dilution to reduce CO trip

Pollutant	Method	Applicability	Advantages	Disadvantages	Net Benefit
ammonia from feed	<i>eliminate</i> select quarry wherever possible	only for new quarries the content should be analysed and consideration given in the Planning Application	real elimination of pollutant to the environment	not always possible and not applicable to existing quarries	If it can be achieved there is a net benefit in selecting or considering such criteria
	<i>minimize</i> consider blending material from different seams or sites	should be applicable as ammonia emission is not a continuous problem	no real reduction of NH <sub>3</sub> release to the environment over the lifetime of the quarry but averaging of NH <sub>3</sub> emission over lifetime allows environmental recovery  reduces need for abatement - abatement can transfer environmental damage elsewhere  facilitates compliance with limits by giving lower average concentrations emitted	no real disadvantage for the environment but manufacturers may have to have a long term strategic plan  also cost of ground survey	helps to achieve low ground and stack concentrations may reduce the need for abatement  averaging dose will allow the environment to recover more easily
	bespoke scrubbers	can be installed at exit	reduce stack and ground level concentrations	It is not a continuous emission - therefore the installation causes more environmental harm than benefit	since it is not a main issue any abatement will cause net damage to the environment

Pollutant	Method	Applicability	Advantages	Disadvantages	Net Benefit
ammonia from feed	<i>render harmless</i> high chimney	applicable to new installation. may be possible to extend some chimneys	reduced ground level concentration slight reduction in operating power due to stack effect	visual impact	real reduction in ground level concentration and real reduction in power consumption
	high gas exit temperature	applicable to both new and existing plants	good dispersion hence low ground level concentration	inefficient cement production increase in fuel usage hence increased emissions	negative real benefit as more fuel is used
	air dilution	all sites	low ground level and stack concentrations low CO trip from ESP	increased energy use low stack exit temperature leading to poorer dispersion	In general no net benefit but worth considering for interim air dilution to reduce CO trip
particulates from feed	<i>eliminate</i> grind coarse	applicable to both new and old	less particulate carried over by the flue gas abatement is easier less energy used in grinding	poorer efficiency therefore greater SO <sub>2</sub> , NO <sub>x</sub> , and CO <sub>2</sub> emissions	adverse energy use net damage to the environment
	control of fugitive emissions	all sites but less so for wet processes also applicable to clinker milling and cement packaging and transport within site	real reduction in particulate emissions  Improved overall efficiency of the plant  Improved visual impact of site and vicinity	possible energy cost in collecting particulate at transfer points	real environmental benefit in reduction of particulate release to the environment  Improved visual impact of site and vicinity  Improved efficiency resulting in reduced emissions of NO <sub>x</sub> , CO <sub>2</sub> , etc

Pollutant	Method	Applicability	Advantages	Disadvantages	Net Benefit
particulates from feed	change process from dry towards wet	not applicable on a kiln basis for existing kilns and also may not be applicable for some feed material possible to transfer production from dry to wet on a company and site basis	real reduction in particulate release to the environment  less energy expended in grinding and transport within the process (pumping)	energy penalty therefore increased fuel use resulting in more NO <sub>x</sub> and CO <sub>2</sub> environmentally unfriendly use of water visual impact (steam emissions)	net damage to the environment
	<i>minimize</i> abatement - ESP - bag filter - gravel bed filter - cyclone	applicable as an end of pipe solution to new and existing sites	minimizes emissions low stack and ground level concentrations	energy penalty performance depends on type of equipment creates landfill problem	dependent on the type of equipment - best option so far is ESP
	improve process control - cyclone performance	applicable to kilns with pre-heaters or calciners also to wet kilns as a retro fit	real reduction in particulate release improved plant efficiency by being able to recirculate more	energy penalty due to possible increase in pressure drop in cyclone	net benefit is kiln dependent and improvement need to be assessed on a kiln by kiln basis potential for real benefit
	<i>render harmless</i> high chimney	applicable to new installation, may be possible to extend some chimneys	reduced ground level concentration slight reduction in operating power due to stack effect	visual impact	real reduction in ground level concentration and real reduction in power consumption
	high gas exit temperature	applicable to both new and existing plants	good dispersion hence low ground level concentration	inefficient cement production increase in fuel usage hence increase emissions	negative real benefit as more fuel is used
	air dilution	all sites	low ground level and stack concentrations low CO trip from ESP	increased energy use low stack exit temperature leading to poorer dispersion	In general no net benefit but worth considering for interim air dilution to reduce CO trip



Pollutant	Method	Applicability	Advantages	Disadvantages	Net Benefit
heavy metals from feed	<i>Eliminate</i> select quarry	mainly for new quarries - key is to consider this at the beginning	real environmental benefit and reduction in heavy metal	not always possible	real reduction in heavy metal if achievable
	<i>Minimise</i> blend low metal feed	It may not be available - consider total survey of the quarry and plan quarrying for blending	no real reduction of heavy metal release to the environment over the lifetime of the quarry but averaging of heavy metal emission over lifetime allows environmental recovery  reduces need for abatement - abatement can transfer environmental damage elsewhere  facilitates compliance with limits by giving lower average concentrations emitted	no real disadvantage for the environment but manufacturers may have to have a long term strategic plan also cost of ground survey	helps to achieve low ground and stack concentrations may reduce the need for abatement It will allow the environment to recover load concentration
	Abatement as for particulate and scrutiny for vapour phase metals	applicable as for particulates abatement and scrubber. These are end of pipe solution	reduce stack and ground level concentration  help to meet the limits set	any additional scrubbing will have a energy penalty and hence CO <sub>2</sub> /SO <sub>2</sub> , NOX emission to the total environment	abatement as a part of particulate will have benefit, but any additional abatement for heavy metal will have a net environment harm as the concentration are low

Pollutant	Method	Applicability	Advantages	Disadvantages	Net Benefit
heavy metals from feed	<i>Render Harmless</i> High Chimney	applicable to new installation. may be possible to extend some chimneys	reduced ground level concentration slight reduction in operating power due to stack effect	visual impact	real reduction in ground level concentration and real reduction in power consumption
	high gas exit temperature	applicable to both new and existing plants	good dispersion hence low ground level concentration	inefficient cement production increase in fuel usage hence increase emissions increase temperature may cause some heavy metal to be in vapour phase and hence will not be in the particulate to be trapped	negative real benefit as more fuel is used
Particulate from fuel mainly for preheat requirement	<i>eliminate</i> use gas, light oil or SF to reduce requirement for preheat  particulate in fuel to the kiln will have no significant effect to the final kiln exit gas  fugitive coal dust leak	<ul style="list-style-type: none"> <li>- applicable to most sites</li> <li>- availability of gas and the price will be the limiting factor</li> <li>- guaranteed supply will not be available</li> <li>- still require standby fuel and associated issues</li> </ul>	minor reduction from coal or oil fired fuel pre heaters  deduction in CO <sub>2</sub> , SO <sub>2</sub> , NOX and particulate	<ul style="list-style-type: none"> <li>- fuel cost</li> <li>- If gas is used explosion hazard</li> <li>- fugitive methane leak</li> </ul>	there is net benefit in reduction of particulate emission from coal fired pre heater stacks  reduction in CO <sub>2</sub> /SO <sub>2</sub> /NOX and particulate

Pollutant	Method	Applicability	Advantages	Disadvantages	Net Benefit
Particulate from fuel mainly for preheat requirement	reduce fugitive emission of coal dust from handling	applicable to all sites with coal or pit-coke burning	real reduction in particulate emission visual impact of site and plant  fuel efficiency improvement due to reduction in fuel loss  reduction in dust explosion risk	none	real improvement particulate emission  reduction in explosion risk
	improve plant efficiency by reducing gas exit temperature  use better heat exchangers	applicable to most processes, theoretically but need to consider each case separately	real reduction in plant efficiency and associated emission to the environment	low gas exit temperatures will require greater fan power to transport gas due to the reduction in stack lift  low gas exit temperature will lead to high ground level concentration resulting from lack of dispersion	possibility of net benefit but need to exam it in detail
	<i>minimise</i> abatement techniques	there are abatement techniques available which are not suitable for cement industry particularly considering the quantity of CO <sub>2</sub> producers	reduction in CO <sub>2</sub> emission	not an environmentally friendly option  high energy used, the process is to drive CO <sub>2</sub> away from CaCO <sub>3</sub> , it is not a real option	it is not a practical and environmentally sound idea. Thermodynamic not a sound idea
	<i>render harmless</i> high chimney	applicable to new installation, may be possible to extend some chimneys	reduced ground level concentration slight reduction in operating power due to stack effect	visual impact	real reduction in ground level concentration and real reduction in power consumption

Pollutant	Method	Applicability	Advantages	Disadvantages	Net Benefit
Particulate from fuel mainly for preheat requirement	high gas exit temperature	applicable to both new and existing plants	good dispersion hence low ground level concentration	inefficient cement production increase in fuel usage hence increase emissions	negative real benefit as more fuel is used
	air dilution	all sites	low ground level and stack concentrations low CO trip from ESP	increased energy use low stack exit temperature leading to poorer dispersion	in general no net benefit but worth considering for interim air dilution to reduce CO trip
SO <sub>2</sub> from fuel	<i>Eliminate</i> move towards dry process	not applicable to all sites and feed available	minor improvement in the SO <sub>2</sub> emission	none if it is achievable	If applicable real reduction SO <sub>2</sub> and CO <sub>2</sub> as improvement in kiln efficiency
	use fuel with no pre heat requirement such as gas or SF	applicable to most sites and kilns	reduction in SO <sub>2</sub> /CO <sub>2</sub> NO <sub>x</sub> from fuel pre heaters reduction in electrical energy user	none	real reduction of SO <sub>2</sub> , NO <sub>x</sub> , CO <sub>2</sub>
	<i>minimise</i> abatement	applicable to wet kiln, and any fuel pre heaters	reduction in SO <sub>2</sub>	transferring environment problem to elsewhere in the country high electrical power use reduction in gas exit temperature visual impact high CO <sub>2</sub> GLC	no real net benefit to the environment likely harm
	<i>render harmless</i> high chimney	applicable to new installation, may be possible to extend some chimneys	reduced ground level concentration slight reduction in operating power due to stack effect	visual impact	real reduction in ground level concentration and real reduction in power consumption

Pollutant	Method	Applicability	Advantages	Disadvantages	Net Benefit
SO <sub>2</sub> from fuel	high gas exit temperature	applicable to both new and existing plants	good dispersion hence low ground level concentration	inefficient cement production increase in fuel usage hence increase emissions inefficient fuel pre heating resulting in increased emission	negative real benefit as more fuel is used
	air dilution	all sites	low ground level and stack concentrations low CO trip from ESP for wet kiln only	increased energy use low stack exit temperature leading to poorer dispersion	in general no net benefit but worth considering for interim air dilution to reduce CO trip for wet kiln only
CO <sub>2</sub> from fuel	eliminate use low carbon fuel natural gas, SF	applicable to all sites, the gas option is difficult as it is not always possible to secure guaranteed supply of gas. The use of SF or similar fuel with low carbon and high H <sub>2</sub> is applicable	- real reduction of CO <sub>2</sub> - benefit in kiln efficiency as these fuel are more controllable than pulverised coal or pet coke real environmental benefit on a global basis if SF can be used	cost implication for gas option	real benefit in considering alternative fuel such as SF on reduction of CO <sub>2</sub> production for town chimney and disposal of SF
	increase plant efficiency	applicable to all plants	real reduction of pollutant of all forms produced for tonne/dm	none	real environmental benefit
	select low CO <sub>2</sub> process such as dry	not applicable to all kilns and influenced by the feed quality and type	real reduction of CO <sub>2</sub>	none within the limit	real reduction of CO <sub>2</sub>
	convert process and feed suitable for dry process	not always possible as some feed contained high water content	thermal efficiency improvement and reduction of CO <sub>2</sub>	the treatment of feed will have adverse environmental effect ie high energy cost	overall no significant benefit but each case needs to be examined and justified

Pollutant	Method	Applicability	Advantages	Disadvantages	Net Benefit
NOx from fuel	eliminate use low Nitrogen fuel in catcher as well as in kiln	applicable to all kilns	real reduction in NOx	cost implication	some benefit but major NOx production is from thermal NOx from air
	combustion control control excess air	to all kilns	real reduction in NOx energy efficiency limit reduced fuel use resulting CO <sub>2</sub> reduction	excessive control could lead to CO trip of the ESPs and kiln instability	real reduction of NOx emission
	use fuel with more controllable feature such as gas, light oil or SF	applicable to most kilns, however gas supply will not be guaranteed. Hence alternative fuel will be required	- real reduction of NOx - possible kiln efficiency improvement available resulting low CO <sub>2</sub> emission low CO <sub>2</sub> emission from low to carbon fuel	the use of intercept gas supply will result in kiln operation change gas explosion HAZARD fugitive gas leak	net benefit from controllable fuel natural gas may not be the first option compared to SF and other controllable fuel
	coal milling fine grinding	applicable for coal fired installation	real reduction in NOx production reduced fuel transport lost	high energy cost of milling increased fugitive emission dust explosion hazard	perceived net benefit but the option needs to be examined in detail likely to result in some benefit
	feed preparation mill feed finely to get better heat transfer and the need for high flame separation	applicable to all kilns most suited for dry kilns	reduction in NOx production improved plant efficiency hence reduce fuel consumption better pre heat transfer	high energy use for milling hence CO <sub>2</sub> emission high particulate emission via stack high fugitive particular emission low gas exit temperature hence high GLC	perceived net benefit, but the options need to be examined in detail has potential to reduce NOx emission

Pollutant	Method	Applicability	Advantages	Disadvantages	Net Benefit
NOx from fuel	Low NOx burners	applicable to oil kilns in general but limited use with coal or pet coke as 25% combustion air is required for fuel transport	reduction in NOx production	<ul style="list-style-type: none"> <li>- longer burning zone with lower temperature</li> <li>- potential to increase dioxin production</li> <li>- If the burning zone is increased it reduces the area/space available for heat transfer to heat feed material hence possible loss in plant efficiency</li> <li>lower temperature will result in poor heat transfer loss in efficiency</li> <li>possible to affect clinker quality. There are a number of different types of clinker produced some of may be affected</li> </ul>	<p>Information available claim benefit of NOX reduction. The net environmental benefit is not fully analysed. It is possible that it may not deliver the full benefit</p> <p>this should be considered on a site by site and kiln by kiln basis</p>
	process modification to integrate 3R concept	less applicable to wet process. For these processes additional pre- heating will need to be included. Best suited for kilns with pre calciners and pre heaters	Potential to reduce NOx	<p>It relies on maintaining reducing atmosphere. It will generate high CO in the flue gas which needs to be oxidised downstream.</p> <p>This will increase the CO trips of the ESPs. Possible CO explosions in the ESP. Additional fans and fuel pumps required. It creates low temperature burning which is conducive to form dioxins.</p>	<p>Net benefit of reducing NOX for the cost of increase CO trips or possible ESP explosions and dioxin formation.</p> <p>It should be considered and the perceived disadvantages evaluated</p>
	Fuel efficiency	applicable to all kilns	real reduction in NOx production	reduction in gas exit temperature resulting in poor dispersion high GLC of CO <sub>2</sub>	net benefit in NOx for CO <sub>2</sub> formation. Should be considered

Pollutant	Method	Applicability	Advantages	Disadvantages	Net Benefit
NOx from fuel	minimise NH <sub>3</sub> injection	applicable to all kilns	reduce stack and GLC of NOx  help to meet the limit	It requires between 2-4 moles of NH <sub>3</sub> to abate 1 mole of NOx for 80% reduction Ref 106  fugitive heat of NH <sub>3</sub> accidental leak and serious harm to public and works.  environmental transport from cost increase CO emission high operating cost Ref 106	It is not a real option with respect to integrated environmental impact as the production of NH <sub>3</sub> by the Haber process starts with N <sub>2</sub> and H <sub>2</sub> which need to be manufactured as well  significant total environmental harm
	carbon filter	applicable to all kilns in theory but it has potential to cause other harm	reduce stack and GLC of NOx help to meet the limit	reduce the flue gas temperature  If used before ESP plant will increase CO trips  carbon dust explosion  the carbon used in the filter is burned with kiln which increases C concentration with fuel, hence CO <sub>2</sub> pollution. If used after ESP then increase in particulate emission	Perceived benefit no actual net benefit to the environment  particularly the CO <sub>2</sub> cost of production and destruction of carbon for the filter bed is considered



Pollutant	Method	Applicability	Advantages	Disadvantages	Net Benefit
NOx from fuel	scrubber	applicable to all kilns	reduce stack and ground level concentration of NOx  help meet the limit	it requires absorbing agent which has a manufacturing environmental cost  absorbent such as NH <sub>3</sub> OH require flue gas to be cooled to less than 100°C  visual impact of steam  low flue gas exit temperature lead to GLC increase of CO <sub>2</sub>	no net environmental benefit by applying this technique
	polvtec process	applicable to all kilns	reduce stack and ground level concentration of NOx  help meet the limit  other reduction SO <sub>2</sub>	again it relies on NH <sub>3</sub> to absorb NOx  this is similar to the problem discussed for NH <sub>3</sub> injection	no net benefit to the total environment as it uses more NH <sub>3</sub> than NOx to absorb NOx
	render harmless high chimney	applicable to new installation. may be possible to extend some chimneys	reduce ground level concentration slight reduction in operating power due to stack effect	visual impact	real reduction in ground level concentration and real reduction in power consumption
	high gas exit temperature	applicable to both new and existing plants	good dispersion hence low ground level concentration	inefficient cement production increase in fuel usage hence increased emissions	negative real benefit as more fuel is used

Pollutant	Method	Applicability	Advantages	Disadvantages	Net Benefit
Nox from fuel	air dilution	all sites	low ground level and stack concentrations low CO trip from ESP	increased energy use low stack exit temperature leading to poorer dispersion	In general no net benefit but worth considering for interim air dilution to reduce CO trip
heavy metal from fuel	<i>eliminate</i> useful with low or no heavy metal	applicable to all kilns providing the alternative fuel can be obtained cost effectively only gas and high oil loss no tar or low metal content metal content in SF can be controlled	perceived reduction of metal emission	reduction in choice of fuel	most of the heavy metal are likely to be captured in the clinker matrix the metal emission is mainly from feed and kiln lining considering the loss of heat exchanger chains with furnace which is likely to have some heavy metal the input from fuel is insignificant
	<i>minimise</i> abatement as part of particulate abatement	applicable for most kilns as part of their particulate abatement	reduction in stack and ground level concentration	energy and the associated CO <sub>2</sub> lost	real benefit as and if it is part of the particulate abatement other form of bespoke abatement are not environmentally efficient for the volume of gases and the very low quantity of emission
	bespoke metal abatement looks for small scale gas clean ups	not applicable for cement works			
Dioxins	<i>eliminate</i> eliminate Cl <sub>2</sub> and aromatic hydrocarbon in fuel	applicable to most kilns providing gas is available	perceived reduction in Dioxin most dioxins formed in kilns are from feed	elimination of suitable fuel from users in the kiln	type of fuel does not change the dioxin emission from the kiln significantly the errors in measurement of dioxin in the flue gas is orders of magnitude greater than any possible change due to fuel this is an inefficient use of effort to control dioxin release

Pollutant	Method	Applicability	Advantages	Disadvantages	Net Benefit
Dioxins	<i>minimise</i> carbon filter and other abatement	applicable as part of the general abatement	perceived reduction in dioxin release from kilns help to project a good image	introduce general inefficiency in clinker production as the need to operate the abatement equipment	no real benefit in reduction in dioxin release since the errors in measurement are in general greater than any contribution from choice of level
	<i>render harmless</i> high chimney	applicable to new installation, may be possible to extend some chimneys	reduced ground level concentration slight reduction in operating power due to stack effect	visual impact	real reduction in ground level concentration and real reduction in power consumption
	high gas exit temperature	applicable to both new and existing plants	good dispersion hence low ground level concentration	inefficient cement production increase in fuel usage hence increased emissions	negative real benefit! as more fuel is used
	air dilution	all sites	low ground level and stack concentrations low CO trip from ESP	increased energy use low stack exit temperature leading to poorer dispersion	In general no net benefit! but worth considering for interim air dilution to reduce CO trip

## APPENDIX B.6 : PROFILES OF ABATEMENT TECHNIQUES FOR CEMENT PROCESSES - COSTS AND APPLICABILITIES

### PARTICULATES (1)

<i>Proposed Technique</i>	<i>Electrostatic Precipitation, or Bag Filtration replacement/up-grade.</i>		
<i>Percent Reduction from current levels</i>	<i>50%-90%</i>		
<i>Achievable Releases</i>	<i>30 mg/Nm<sup>3</sup> for all types of process and all stages of process.</i>		
<i>Cost (2000 tpd plant)</i>	<i>ESP</i>	<i>Capital</i>	<i>£2-4m</i>
		<i>Operating</i>	<i>£50,000 operation £50,000 maintenance</i>
	<i>Bag Filter</i>	<i>Capital</i>	<i>£3-6m £200,000 operation £500,000 maintenance</i>
<i>Cost per tonne</i>	<i>ESP</i>		<i>£0.5-1.0</i>
	<i>Bag filter</i>		<i>£1.7-2.4</i>

NB It is assumed that all the cost of improved particulate control can be attributed to environmental protection. The additional particles collected will tend to be fine, with a high alkali content, limiting the possibility for recycling.

**Key Issues**

- The majority of UK cement plants operate ESPs, but they do not perform to maximum efficiency.

Current emissions:	Wet (with ESP)	4-80 mg/Nm <sup>3</sup>
	Dry (with ESP)	20-50 mg/Nm <sup>3</sup>

ESPs can be up-graded by making the air flow in the ESP more uniform and by adding more elements. Performance can be increased by up to 30-40%. Bag filters, with high temperature media, (steel, ceramic or high temperature polymers) may be used, but individual bags may fail - particularly if reverse jet type - and it is not always possible to detect the failure and replace the bag. Costs of refurbishment are estimated at around £0.4/tonne of cement.

- The 30 mg/Nm<sup>3</sup> should be applied to all types of kiln and all process stages. There should be no derogation for clinker coolers (100 mg/Nm<sup>3</sup> in IPR 3/1).

## PARTICULATES (2)

<i>Proposed Technique</i>	<i>Materials Handling Measures -</i>		<i>dust hoods, closed and covered storage areas.</i>
<i>Percent Reduction from current levels</i>	<i>&gt; 50%</i>		<i>very site specific</i>
<i>Achievable Releases</i>	<i>?</i>		
<i>Cost (2000 tpd plant)</i>	<i>Capital</i>	<i>\$2.3m-5m</i>	
<i>Cost per tonne</i>		<i>£0.5 - £1.2</i>	
<i>Key Issues:</i>	<ul style="list-style-type: none"><li>• Applicable to all processes.</li></ul>		

## SO<sub>2</sub> (1)

*Proposed Technique*                      *Selective quarrying/raw material blending to reduce sulphur content in batch. Limited to availability of deposits. Suitable for both wet and dry processes.*

*Percent Reduction from current levels*                      *Proportional to degree of substitution, and sulphur in materials. Main benefit is evening out peaks in sulphur releases.*

*Achievable Releases*                      *500 - 750 mg/Nm<sup>3</sup> (500 mg/m<sup>3</sup> is Swiss limit)*

*Cost (2000 tpd plant)*                      *Capital            £200,000*  
    *Operating        £100,000*

*Cost per tonne*                      *£0.2*

- Key Issues**
- SO<sub>2</sub> releases are primarily dependent on the nature of the raw material. Releases from the fuel are a small proportion of total releases.
  - Sulphur content of deposits in a quarry can vary from 0.2 to 1.7%, although a range of 0.2 to 0.8% is more typical. This equates to a difference in sulphur content of up to 4 times, from one part of a quarry to another.
  - Quarries already control for 4 mineral parameters, it is therefore technically possible, although perhaps complex, to control for sulphur content as well.
  - One problem is storage capacity which is limited to about 3 days production. Storing large quantities of raw material for future use, would add further costs.
  - **Kiln type** is also important: the use of pre-calciners on dry kilns reduces releases. Wet kilns have higher releases due to a) no pre-heating and pre-calcination, and b) higher fuel consumption.
  - Wet kilns may be converted to dry kilns but the cost of conversion would be similar to that of installing a new dry process. Not considered a viable option. For new processes, the dry process should be installed.

## SO<sub>2</sub> (2)

<i>Proposed Technique</i>	<i>Lime addition into top of pre-heater for dry process. Lime solution added to ESP conditioning water for wet or dry process.</i>	
<i>Percent Reduction from current levels</i>	<i>30-60%</i>	
<i>Achievable Releases</i>	<i>500 - 750 mg/Nm<sup>3</sup> (500 mg/m<sup>3</sup> is Swiss limit)</i>	
<i>Cost (2000 tpd plant)</i>	<i>Capital</i>	<i>£500,000 (estimate of lime storage and conveyor equipment)</i>
	<i>Operating</i>	<i>£100,000-£750,000 (variations depend on amount of lime needed)<sup>1</sup></i>
<i>Cost per tonne</i>	<i>£0.26-£1.2</i>	
<i>Key Issues</i>	<ul style="list-style-type: none"><li>• Savings in downstream lime usage not taken into account. It has not been possible to determine the extent of these savings.</li><li>• 500 - 750 mg/Nm<sup>3</sup> limit is some way below actual emission levels. Current emissions: Dry    500-900 mg/Nm<sup>3</sup> Wet    1800-2400 mg/Nm<sup>3</sup></li></ul>	

If unabated releases are high, in excess of 2500 mg/Nm<sup>3</sup> (equivalent to about 1.5% sulphur content in raw material - on a dry process with cyclone pre-heater), further abatement measures may be necessary.

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<sup>1</sup> Lime consumption based on the following calculations for a 2,000 tpa plant :

### **Release rate : 1000 mg SO<sub>2</sub>/kg clinker**

Stoichiometric Lime consumption	580 mg Ca(OH) <sub>2</sub> /kg clinker
x 6 (amount required in practice)	3.48 g/kg
annual consumption	2,400 tonnes
Cost (@ £40/tonne of lime)	£96,000

### **Release rate : 8000 mg SO<sub>2</sub>/kg clinker**

Stoichiometric Lime consumption	4.6 g Ca(OH) <sub>2</sub> /kg clinker
x 6 (amount required in practice)	27.6 g/kg
annual consumption	18,900 tonnes
Cost (@£40/tonne of lime)	£756,000

### SO<sub>2</sub> (3)

<i>Proposed Technique</i>	<i>"In process" de-sulphurisation - addition of "calcliner" material before ESP and recover in cyclone. For dry process.</i>	
<i>Percent Reduction from current levels</i>	<i>10-20% (not verified)</i>	
<i>Achievable Releases</i>	<i>500 - 750 mg/Nm<sup>3</sup> (500 mg/m<sup>3</sup> is Swiss limit)</i>	
<i>Cost (2000 tpd plant)</i>	<i>Capital</i>	<i>£3-4m</i>
	<i>Operating</i>	<i>£50,000 (as above)</i>
<i>Cost per tonne</i>	<i>£0.8 - £1.0</i>	
<i>Key Issues</i>	<ul style="list-style-type: none"><li>• Not a great deal known about this technique - FL Schmidt design, claim good performance but have no verification.</li></ul>	



## SO<sub>2</sub> (4)

<i>Proposed Technique</i>	<i>FGD - wet or dry (most applicable to wet processes.)</i>	
<i>Percent Reduction from current levels</i>	<i>50-80%</i>	<i>Dry FGD</i>
	<i>50-75%</i>	<i>Wet FGD</i>
<i>Achievable Releases</i>	<i>500 - 750 mg/Nm<sup>3</sup> (500 mg/m<sup>3</sup> is Swiss limit)</i>	
<i>Cost (2000 tpd plant)</i>	<i>Capital</i>	<i>£4-8m Dry FGD</i>
		<i>£8-10m Wet FGD (not verified)</i>
	<i>Operating</i>	<i>Dry £900,000 (0.01t/CaOH per tonne clinker @ £60/tonne, plus other operating costs)</i>
		<i>Wet £2.9m</i>
<i>Cost per tonne</i>	<i>£2.2-3.1</i>	<i>Dry FGD</i>
	<i>£6-6.4</i>	<i>Wet FGD</i>
<i>Key Issues</i>	<ul style="list-style-type: none"> <li>• Achievable releases. Average concentration of releases from Swiss plant is 423 mg/m<sup>3</sup>.</li> <li>• Cost. Lower capital cost estimates based on supplier data, higher cost estimates based on Swiss plant (1900tpd).</li> <li>• Wet FGD is typically twice the cost of dry FGD.</li> </ul>	

## NOx (1)

<i>Proposed Technique</i>	<i>Combustion control for wet or dry processes.</i>	
	<i>a) Low NOx burners</i>	
	<i>b) Oxygen concentration (maintain back end concentration of around 1.5% O<sub>2</sub>)</i>	
<i>Percent Reduction from current levels</i>	<i>0-20% (Actual trials have shown relatively little reduction in NOx levels)</i>	
<i>Achievable Releases (max)</i>	<i>Wet</i>	<i>depends on combination of measures</i>
	<i>Dry</i>	<i>depends on combination of measures</i>
<i>Cost (2000 tpd plant)</i>	<i>Capital</i>	<i>£750,000 (for low NOx burners) £150,000 (for O<sub>2</sub> control system)</i>
	<i>Operating</i>	<i>£50 - £90K (due to higher pressure fans and higher maintenance costs)</i>
<i>Cost per tonne</i>	<i>£0.25 - 0.3</i>	

<i>Key Issues</i>	<ul style="list-style-type: none"> <li>• Applicable to all kilns, but limited use with coal or pet-coke as 25% combustion air is required for pneumatic fuel transport.</li> <li>• Need for O<sub>2</sub> concentration control on back end of kiln, due to trade off with SO<sub>2</sub> and CO formation. Although NOx decreases as excess air is reduced, both SO<sub>2</sub> and CO increase. As excess air decreases more sulphates (SO<sub>3</sub>) in the clinker are reduced to gaseous SO<sub>2</sub>. In addition, lower excess air can lead to greater CO formation and ESP trips.</li> <li>• Reduction in NOx of around 30% from current levels is potentially achievable, although tests on some kilns have shown much less improvement.</li> <li>• Has potential to increase dioxin production due to longer burning zone - has not been quantified.</li> <li>• May decrease plant efficiency due to (i) extended burning zone, which reduces the length of the drying zone of the kiln and heat transfer efficiency, and (ii) lower temperature. Lower temperature may also affect clinker quality.</li> </ul>
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## NOx (2)

*Proposed Technique*      *Fuel Selection - alternatives to coal (tyres, liquid, gaseous fuels). Suitable for wet and dry processes.*

*Percent Reduction from current levels*

<i>Wet</i>	<i>25-45% (SLF)</i>
<i>Wet</i>	<i>55% (tyre chip substitution)</i>
<i>Dry</i>	<i>10-30% (SLF)</i>

*Achievable Releases (max)*

<i>Wet</i>	<i>depends on combination of measures</i>
<i>Dry</i>	<i>depends on combination of measures</i>

*Capital cost (2000 tpd plant)*      *£750,000 (conversion to liquid/gaseous fuel burners)*

<i>Operating Costs :</i>	<i>SLF (low price differential)</i>	<i>£0.07-0.22/tonne SAVING</i>	<i>(3-9% substitution)</i>
	<i>SLF (high price differential)</i>	<i>£0.2-£0.55/tonne SAVING</i>	<i>(3-9% substitution)</i>
	<i>Tyres</i>	<i>£0.2-£0.5 SAVING</i>	<i>(2-6% substitution)</i>

*For comparison:*

<i>Pet-coke (low)</i>	<i>£0.4-0.6/tonne SAVING</i>	<i>(pet-coke 55-65% cost of coal per unit energy, assume 10% substitution)</i>
<i>Pet-coke (high)</i>	<i>£2-3/tonne SAVING</i>	<i>(pet-coke 55-60% cost of coal per unit energy, assume 50% substitution)</i>

The net costs of installing new burners can be reduced if timed to coincide with scheduled replacement of existing fuel feeding systems.

*Key Issues*

- SLF can produce higher particulate, metal and 'dioxin emissions, but economic arguments are strong for using SLF.
- Tyre chips widely used in Germany in cement kilns and have proven reductions in NOx. CO formation has to be carefully controlled.
- Pet-coke contains higher quantities of both Sulphur and Nitrates than coal. Pet-coke typically **increases** NOx by 20-30% compared with coal (Source: FL Smidth).

### NOx (3)

<i>Proposed Technique</i>	<i>Staged Combustion</i>	<i>For use on dry kilns with pre-calciners. Fuel introduced into the pre-calciner to create reducing conditions. The partially combusted fuel and gas mixture then needs to be fully oxidised in the second half of pre-calciner.</i>
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<i>Percent Reduction from current levels</i>	<i>Wet</i>	<i>not applicable</i>
	<i>Dry</i>	<i>10-20% (wrt to kiln with existing pre-calciner)</i>

<i>Achievable Releases (max)</i>	<i>Wet</i>	<i>n/a</i>
	<i>Dry</i>	<i>500 mg/Nm3 (Swedish plant)</i>

<i>Cost (2000 tpd plant)</i>	<i>Capital</i>	<i>£1.5m</i>
	<i>Operating</i>	<i>£750,000</i>

<i>Net Cost per tonne</i>	<i>£1.4</i>
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*Key Issues:*

- Need to control CO level to avoid ESP trips.
- Example of such a process in Sweden

#### NOx (4)

<i>Proposed Technique</i>	<i>SNCR</i>	<i>Injection of ammonia/urea at a point where temperature is in the required 800-1100°C range for NOx reduction. Suitable point may be at exit of pre-calciner on a dry kiln. Technique not suitable for wet processes.</i>
<i>Percent Reduction from current levels</i>	<i>Wet</i>	<i>no empirical data available - (approximate range 10-40%)</i>
	<i>Dry</i>	<i>40% (with respect to kiln with existing pre-calciner - FLS study)</i>
<i>Achievable Releases (max)</i>	<i>Wet</i>	<i>&lt; 500 mg/Nm<sup>3</sup> (current average for wet kiln is 670 mg/Nm<sup>3</sup>)</i>
	<i>Dry</i>	<i>&lt; 500 mg/Nm<sup>3</sup> (Swedish plant)</i>
<i>Cost (2000 tpd plant)</i>	<i>Capital</i>	<i>£0.75m - £1.5 m</i>
	<i>Operating</i>	<i>£150K - £350K</i>
<i>Net Cost per tonne</i>	<i>£0.6 /tonne</i>	

#### Key Issues:

- Need to control CO and NH<sub>3</sub> release levels to avoid ESP trips and ammonia slippage.
- Little practical evidence of technique on cement kilns.

## NOx/SO<sub>2</sub>/Metals/Dioxins

<i>Proposed Technique</i>	<i>POLVITEC</i>	<i>2 stage carbon filter, which is preceded by an ammonia injection stage. Carbon flows counter current to air flow. Carbon adsorbs unreacted ammonia as well as metals and SO<sub>2</sub>. Suitable for wet or dry process.</i>	
<i>Percent Reduction from current levels</i>	<i>Wet</i>	<i>no empirical data available</i>	
	<i>Dry</i>	<i>&gt; 80% (wrt to kiln with existing 4 stage pre-calciner)</i>	
<i>Achievable Releases (max)</i>	<i>Wet</i>	<i>not known</i>	
	<i>Dry</i>	<i>NOx</i>	<i>800 mg/Nm3</i>
		<i>SO<sub>2</sub></i>	<i>100 mg/Nm3</i>
		<i>Metals</i>	<i>5 ug/Nm3</i>
<i>Cost (2000 tpd plant)</i>	<i>Capital</i>	<i>£10-15m</i>	
	<i>Operating</i>	<i>£1.75m</i>	
<i>Net Cost per tonne</i>	<i>£4.5-6 /tonne</i>		
<i>Key Issues:</i>	<ul style="list-style-type: none"><li>● Very high capital cost.</li><li>● Limited data on abatement of NOx, metals and chlorine compounds from other kilns.</li><li>● Unproven on wet kilns</li></ul>		

## Dioxins

<i>Proposed Technique</i>	<p>1. <i>Control chlorine content in fuels. Current SLF standards appear adequate.</i></p> <p>2. <i>Abatement. Better particulate abatement reduces dioxin releases. Where releases are higher than limit, abatement should be fitted. Improved quenching of gases.</i></p>	
<i>Percent Reduction from current levels</i>	<i>Wet</i> <i>Dry</i>	<i>not known</i> <i>not known</i>
<i>Achievable Releases (max)</i>	<i>Wet</i> <i>Dry</i>	<i>0.1 ng/m3</i>
<i>Cost (2000 tpd plant)</i>	<i>Costs Included in other techniques</i>	
<i>Net Cost per tonne</i>	<i>As for particulates</i>	
<i>Key Issues:</i>	<ul style="list-style-type: none"> <li>• The majority of dioxins are formed in the ESP. Therefore, temperature at the ESP inlet must be kept low, below 200°C.</li> <li>• Little is known about the potential for dioxin formation during clinker cooling.</li> </ul>	

**APPENDICES C.1 - C.5**



**APPENDIX C.1 : SUMMARY OF RELEASES FROM LIME PROCESSES**

Process Stage	Released Substance					
	Particulate Matter	Acid Gases		Heavy Metals	Dioxins	Others
		NOx	SO <sub>2</sub>			
raw material handing and preparation	A/w					
crushing and screening	A/w					
raw material storage	A					
fuel preparation (coal handling)	A	A	A			
gas transport (pump costs + leakage)						CO <sub>2</sub> and methane
kiln burning	A	A	A	A	A	CO <sub>2</sub>
burnt lime storage	A/w					
hydrator	A, w					steam
packaging and dispatch	A, l					
air pollution abatement plant	l					w

Key:            prescribed substances to:    Air (A), Water (W), Land (L)  
                   other substances to:        air (a), water (w), land (l)

**APPENDIX C.2 : OPTIONS FOR CONTROLLING RELEASES FROM LIME PROCESSES - RAW MATERIALS**

Pollutant	Eliminate	Minimize	Render Harmless
SO <sub>2</sub>	<p>select quarry whenever possible</p> <p>most of the SO<sub>2</sub> is from the feed rather than from the fuel</p>	<p>consider blending with low S feed</p> <p>FGD</p> <p>kiln design: shaft kilns most S recombines with burnt lime</p> <p>select combustion conditions</p> <p>vortex scrubbers</p> <p>heat exchanger redesign</p>	<p>chimney</p> <p>gas exit temperature to ensure dispersion</p>
NH <sub>3</sub>	<p>select quarry whenever possible - most quarries have no problem with NH<sub>3</sub></p>	<p>consider blending material from other sites</p>	<p>chimney gas exit temperature</p>
VOC, TOC	<p>select, screen, or blend if possible</p>	<p>afterburn, use afterburner at exit of process</p>	<p>high chimney and high gas temperature</p>
particulate and heavy metal	<p>process/quarry selection</p> <p>crush coarse</p> <p>penalty is poor heat transfer and high gas temperature resulting in low efficiency and more NO<sub>x</sub>, SO<sub>2</sub>, CO<sub>2</sub></p>	<p>abatement eg ESP bag filters etc</p> <p>most heavy metals come from the feed so there is the potential for blending or selecting</p>	<p>high chimney and high gas temperature</p>

### APPENDIX C.3 : OPTIONS FOR CONTROLLING RELEASES FROM LIME PROCESSES - FUEL

Pollutant	Eliminate	Minimize	Render Harmless
particulate	<p>use gas and liquid fuel with low ash</p> <p>use SF or gas to replace coal the use of coal requires separate air heater which is a small source of particles</p>	<p>use abatement equipment for coal fired heaters</p>	<p>high chimney and high gas temperature for good dispersion</p>
CO <sub>2</sub>	<p>use low carbon fuel</p> <p>natural gas</p> <p>SF</p> <p>increase plant efficiency</p> <p>select high efficiency process</p> <p>low exit temperatures, improve plant efficiency</p>	<p>there are a number of CO<sub>2</sub> abatement techniques available but none is considered to be environmentally efficient</p>	<p>high chimney and high gas temperature for good dispersion</p>
SO <sub>2</sub>	<p>S in fuel has effect on the SO<sub>2</sub> emission so select low S fuel</p> <p>elimination of SO<sub>2</sub> is from the use of fuel with no pre-heat requirement, ie SF, gas, oil</p>	<p>improve plant efficiency to reduce fuel requirement</p> <p>SO<sub>2</sub> abatement</p>	<p>high chimney and high gas temperature for good dispersion</p>

**APPENDIX C.3 : (Cont'd)**

Pollutant	Eliminate	Minimize	Render Harmless
NO <sub>x</sub>	<p>use low nitrogen fuel</p> <p>combustion control: excess air fuel properties</p> <p>feed preparation - better control of feed size and feed/fuel mix</p> <p>low NO<sub>x</sub> burner</p> <p>fuel efficiency</p> <p>process modification 3R concept modified for lime kilns</p>	<p>NH<sub>3</sub> injection</p> <p>carbon filter</p> <p>scrubber</p> <p>POLVITEC process</p>	<p>high chimney and high gas temperature for good dispersion</p>
heavy metals	<p>use fuel with low heavy metal content</p>	<p>select suitable process?</p> <p>abatement ESP and others applicable to particulate</p>	<p>high chimney and high gas temperature for good dispersion</p>
dioxins	<p>eliminate Cl in fuel</p>	<p>carbon filter</p> <p>abatement</p>	<p>high chimney and high gas temperature for good dispersion</p>

**APPENDIX C.4 : SUMMARY OF ABATEMENT TECHNIQUES FOR LIME PROCESSES - COSTS AND APPLICABILITIES**

**PARTICULATES (1)**

<i>Proposed Technique</i>	<i>Electrostatic Precipitation, Bag Filtration, or Wet Scrubber</i>		
<i>Percent Reduction from current levels</i>	<i>50%-90%</i>		
<i>Achievable Releases</i>	<i>30 mg/Nm<sup>3</sup> for all types of process and all stages of process. There are good examples in the UK of discharge concentrations below this being consistently achieved using the first two techniques.</i>		
<i>Cost (100 H\ld plant)</i>	<i>ESP</i>	<i>Capital</i>	<i>£1-3M £5-15k operation £10k maintenance</i>
	<i>Bag Filter</i>	<i>Capital</i>	<i>£2-4M £100k operation £500k maintenance</i>
	<i>Wet Scrubber</i>	<i>Capital</i>	<i>£1-1.5M £100k operation £200k maintenance)</i>
<i>Cost per tonne</i>	<i>ESP</i>	<i>£5.0 - £14 (replacement) £3.0 - £5.0 (up-grade)</i>	
	<i>Bag Filter</i>	<i>£26 - £36 (replacement). £3.0 - £5.0 (up-grade)</i>	
<i>Key Issues</i>	<p>Only some of UK lime plants operate ESPs; in general ESPs do not perform to maximum efficiency.</p> <p>ESPs can be up-graded by making the air flow in the ESP more uniform and by adding more elements. Performance can be increased by up to 30-40%. Bag filters, with high temperature media (steel, ceramic or high temperature polymers) may be used, but individual bags may fail - particularly if reverse jet type - and it is not always possible to detect the failure and replace the bag.</p>		
<i>Applicability</i>	<p>Applicable to all kilns but as most of these are vertical kilns there may be some extensive duct work required to accommodate the big abatement equipment.</p>		

## PARTICULATES (2)

<i>Proposed Technique</i>	<i>Materials Handling Measures - Dust hoods, closed and covered storage areas</i>	
<i>Percent Reduction from current levels</i>	<i>&gt; 70% very site specific</i>	
<i>Achievable Releases</i>	<i>&gt; 80 Tonne/per year</i>	
<i>Cost (100 t/d plant)</i>	<i>Capital</i>	<i>£4-6M</i>
<i>Cost per tonne</i>	<i>£19 - £28</i>	
<i>Key Issues</i>	The dust generated by handling the processed material is high. The CaO dust is about half as light as the dust from raw material or cement. Furthermore it breaks down to form dust more easily. Therefore the fugitive dust generation in lime industry is greater than that for the cement kiln.	
<i>Applicability</i>	Applicable to all sites and all processes. It is vital to reduce the dust level for the workers.	

## SO<sub>2</sub> (1)

<i>Proposed Technique</i>	<i>Selective quarrying/raw material blending to reduce sulphur content in batch. Limited to availability of deposits. Suitable for all types of kilns.</i>	
<i>Percent Reduction from current levels</i>	<i>Proportional to degree of substitution and sulphur in materials. Maximum feasible, 50% reduction is possible as the feed can change by a factor of 4 between feeds.</i>	
<i>Achievable Releases</i>	<i>Less than 400 mg/Nm<sup>3</sup></i>	
<i>Cost (100 t/d plant)</i>	<i>Capital</i>	<i>£200k</i>
	<i>Operating</i>	<i>£80k</i>
<i>Cost per tonne</i>	<i>£3.0</i>	
<i>Key Issues</i>	<i>SO<sub>2</sub> releases are primarily dependent on the nature of the raw material. Releases from the fuel are significant for the lime industry. SO<sub>2</sub> in theory can react with CaCO<sub>3</sub> and produces CO<sub>2</sub> and CaSO<sub>3</sub>, but the flow put through the feed material, the temperature and the lack of H<sub>2</sub>O to complete the reactions makes this reaction slow. The lime process is often operated such as to drive the SO<sub>2</sub> off as sulphur content in the product is not desirable.</i>	
<i>Applicability</i>	<i>Feed is already selected to ensure suitable feed. This is achievable by carrying out a full survey.</i>	

## SO<sub>2</sub> (1)

<i>Proposed Technique</i>	<i>Lime addition into the flue gases for all lime kilns are possible. Lime solution can be taken from slakers and added to ESP conditioning water before ESPs.</i>	
<i>Percent Reduction from current levels</i>	<i>30-60%</i>	
<i>Achievable Releases</i>	<i>Less than 400 mg/Nm<sup>3</sup></i>	
<i>Cost (100 t/d plant)</i>	<i>Capital</i>	<i>£800k (estimate of lime storage and conveyor equipment)</i>
	<i>Operating</i>	<i>£30k</i>
<i>Cost per tonne</i>	<i>£ 5.0</i>	
<i>Key Issues</i>	<i>There is a large amount of waste lime recoverable from fugitive emissions which can be used for lime addition to the water spray.</i>	
	<i>Excess addition of lime water will produce visual plume.</i>	
<i>Applicability</i>	<i>Applicable to all kilns.</i>	



## SO<sub>2</sub> (3)

<i>Proposed Technique</i>	<i>FGD - wet or dry</i>	
<i>Percent Reduction from current levels</i>	<i>50-80% Dry FGD 50-75% Wet FGD</i>	
<i>Achievable Releases</i>	<i>Less than 400 mg/Nm<sup>3</sup> (average release)</i>	
<i>Cost (100 t/d plant)</i>	<i>Capital</i>	<i>£3-6M Dry FGD £6-8M Wet FGD (not verified)</i>
	<i>Operating</i>	<i>£400k (low quality lime should be available free from the process)</i>
<i>Cost per tonne</i>	<i>£25 - £39 (dry) £39 - £48 (wet)</i>	
<i>Key Issues</i>	<ul style="list-style-type: none"><li>• Wet FGD typically twice the cost of dry FGD.</li><li>• Very high capital and running costs, although the lime for the process should be available from site works.</li></ul>	
<i>Applicability</i>	<ul style="list-style-type: none"><li>• Applicable to all types of kilns if cost effective.</li></ul>	

## NO<sub>x</sub> (1)

<i>Proposed Technique</i>	<i>Combustion control applicable to all kilns.</i>	
	a)	<i>Low NOx burners</i>
	b)	<i>Oxygen concentration control</i>
<i>Recent Reduction from current levels</i>	<i>~30%</i>	
<i>Achievable Releases (max)</i>	<i>All kilns. 600 mg/Nm<sup>3</sup></i>	
<i>Cost (100 t/d plant)</i>	<i>Capital</i>	<i>£500k for burner but there are a number of burners £200k (for O<sub>2</sub> control system with the requirement for product quality)</i>
	<i>Operating</i>	<i>£50k</i>
<i>Cost per tonne</i>	<i>£4.6</i>	
<i>Key issues</i>	<i>Applicable to all kilns, but limited use with coal or pet coke as some coke/coal are feed with the feed.</i>	
	<i>Need for O<sub>2</sub> concentration control on back end of kiln, due to trade off with SO<sub>2</sub> and CO formation. Although NO<sub>x</sub> decreases as excess air is reduced, both SO<sub>2</sub> and CO increase. In addition, lower excess air can lead to greater CO formation and ESP trips.</i>	
	<i>Realistic reduction in NOx of around 30% from current levels is achievable.</i>	
	<i>Has potential to increase dioxin production due to longer burning zone - has not been quantified. This is particularly important for lime kilns as the reaction temperature is low.</i>	
<i>Applicability</i>	<i>Applicable to all kilns.</i>	

## NO<sub>x</sub> (2)

<i>Proposed BAT</i>	<i>Fuel Selection - alternatives to coal (tyres, liquid, gaseous fuels) and Fuel Preparation (grinding of solid fuels).</i>
<i>Percent Reduction from current levels</i>	<i>Not qualified</i>
<i>Achievable Releases (max)</i>	<i>Less than 500 mg/Nm<sup>3</sup>, depends on combination of measures</i>
<i>Capital cost (100 t/d plant)</i>	<i>£800k (conversion to liquid/gaseous fuel burners)</i>
<i>Operating:</i>	<i>SLF positive due to cost savings. Savings for lime kilns are not quantified. (Low sulphur coal) Approximately £30k - £60K.</i>
<i>For comparison:</i>	
<i>Key issues:</i>	<i>SLF can produce higher particulate, metal and 'dioxin emissions, due to poor ESP performance, but economic arguments are strong for using SLF, and the ESP performance can be improved.  Pet-coke contains higher quantities of both Sulphur and Nitrates than coal.</i>
<i>Applicability</i>	<i>Applicable to all kilns in theory, but the product quality is important, any new fuel or family of fuels, requiring approved.</i>

### NO<sub>x</sub> (3)

<i>Proposed Technique</i>	<i>NO<sub>x</sub> Reduction through staged combination.</i>	
<i>Percent Reduction from current levels</i>	<i>&gt;60%</i>	
<i>Achievable Releases (max)</i>	<i>300 mg/Nm<sup>3</sup></i>	
<i>Cost (100 t/d plant)</i>	<i>Capital</i>	<i>£800k</i>
	<i>Operating</i>	<i>£350k (assume 1% additional fuel consumption)</i>
<i>Net Cost per tonne</i>	<i>£14</i>	
<i>Key Issues:</i>	<i>Need to control CO level to avoid ESP trips.</i>	
<i>Applicability:</i>	<i>Applicable to all processes but costs for rotary kilns are likely to be twice as that of other kilns.</i>	

#### NO<sub>x</sub> (4)

<i>Proposed Technique</i>	<i>SNCR Injection of ammonia/urea at a point where temperature is in the required 800-1100°C range for NO<sub>x</sub> reduction.</i>	
<i>Percent Reduction from current levels</i>	<i>&gt;40% claimed</i>	
<i>Achievable Releases (max)</i>	<i>&lt;600 mg/Nm<sup>3</sup></i>	
<i>Cost (100 t/d plant)</i>	<i>Capital</i>	<i>£3-4m NH<sub>3</sub> storage and injection system should be designed and tested</i>
	<i>Operating</i>	<i>£250k</i>
<i>Net Cost per tonne</i>	<i>£21 - £26</i>	
<i>Key Issues:</i>	<i>Need to control CO and NH<sub>3</sub> release levels.</i>	
<i>Applicability:</i>	<i>Not applicable as the NH<sub>3</sub> injection for lime kilns has not been fully tested and proved. NH<sub>3</sub> hazards need to be considered.</i>	

## Dioxins

<i>Proposed Technique</i>	1	<i>Control chlorine content in fuels. Current SLF standards appear adequate.</i>	
	2	<i>Abatement - Better particulate abatement reduces dioxin releases. Where releases are higher than limit, abatement should be fitted.</i>	
<i>Percent Reduction from current levels</i>		<i>Measuring techniques are not adequate to detect any difference.</i>	
<i>Achievable Releases (max)</i>		<i>0.1 ng/m<sup>3</sup></i>	
<i>Cost (100 t/d plant)</i>	<i>Capital</i>	<i>linked to the particulate abatement</i>	
	<i>Operating</i>	<i>same as particulate abatement</i>	
<i>Net Cost per tonne</i>		<i>Not quantified</i>	
<i>Key Issues:</i>		<i>If ESP are installed then the temperature needs to be controlled. High ESP temperatures increase dioxin releases.</i>	
<i>Applicability</i>		<i>Applicable to all processes as part of the particulate abatement technique. Carbon and other filters are available but considering the very high cost they are considered uneconomical.</i>	

**APPENDIX C.5 : SUMMARY OF APPLICABILITY, ADVANTAGES, DISADVANTAGES, AND NET BENEFIT OF CONTROL TECHNIQUES FOR EACH POLLUTANT**

pollutant	method	applicability	advantages	disadvantages	net benefit
SO <sub>2</sub> from feed	<i>Eliminate</i> select quarry	mainly for new quarries - key is to consider this at the beginning	real environmental benefit and reduction in SO <sub>2</sub>	not always possible	real reduction in SO <sub>2</sub> if achievable
	<i>Minimize</i> blending low S feed	It may not be available - consider total survey of the quarry and plan quarrying for blending	no real reduction of SO <sub>2</sub> release to the environment over the lifetime of the quarry but averaging of SO <sub>2</sub> emission over lifetime allows environmental recovery  reduces need for abatement - abatement can transfer environmental damage elsewhere  facilitates compliance with limits by giving lower average concentrations emitted	no real disadvantage for the environment but manufacturers may have to have a long term strategic plan also cost of ground survey	helps to achieve low ground and stack concentrations may reduce the need for abatement  averaging dose will allow the environment to recover more easily
	high temperature	not yet fully understood - further data collection and interpretation of results is needed	may reduce SO <sub>2</sub> at the expense of increasing NO <sub>x</sub> production	increase in NO <sub>x</sub> production	no real benefit can be deduced from the data available so far - further trials are required more likely to be detrimental as a result of NO <sub>x</sub> production
	FGD flue gas desulphurization unit	applicable to most kinds of a very high capital expenditure	will reduce the stack concentrations	lower gas exit temperatures will result in higher CO <sub>2</sub> ground level concentrations and possible higher level concentrations of other gases visual impact	perceived benefit low SO <sub>2</sub> emission from the stack no overall benefit to the global environment is likely, particularly when the operating energy cost and the associated CO <sub>2</sub> and other pollutants are considered
	vortex scrubber	not applicable to lime industry			

pollutant	method	applicability	advantages	disadvantages	net benefit
SO <sub>2</sub> from feed	<i>render harmless</i> high chimney	applicable to new installation, may be possible to extend some chimneys	reduced ground level concentration slight reduction in operating power due to stack effect	visual impact diminishing return on investment	real reduction in ground level concentration and real reduction in power consumption
	high gas exit temperature	applicable to both new and existing plant	good dispersion hence low ground level concentration	inefficient lime production increase in fuel usage hence increased emissions	negative real benefit as more fuel is used
	air dilution	all sites	low ground level and stack concentrations low CO trip from ESP	increased energy use low stack exit temperature leading to poorer dispersion	in general no net benefit but worth considering for interim air dilution to reduce CO trip
ammonia from feed	<i>eliminate</i> select quarry wherever possible	only for new quarries the content should be analysed and consideration given in the Planning Application	real elimination of pollutant to the environment	not always possible and not applicable to existing quarries	if it can be achieved there is a net benefit in selecting or considering such criteria
	<i>minimize</i> consider blending material from different seams or sites	should be applicable as ammonia emission is not a continuous problem	no real reduction of NH <sub>3</sub> release to the environment over the lifetime of the quarry but averaging of NH <sub>3</sub> emission over lifetime allows environmental recovery  reduces need for abatement - abatement can transfer environmental damage elsewhere  facilitates compliance with limits by giving lower average concentrations emitted	no real disadvantage for the environment but manufacturers may have to have a long term strategic plan also cost of ground survey	helps to achieve low ground and stack concentrations may reduce the need for abatement  averaging dose will allow the environment to recover more easily
	bespoke scrubbers	can be installed at exit	reduce stack and ground level concentrations	it is not a continuous emission - therefore the installation causes more environmental harm than benefit	since it is not a main issue any abatement will cause net damage to the environment



pollutant	method	applicability	advantages	disadvantages	net benefit
ammonia from feed	<i>render harmless</i> high chimney	applicable to new installation. may be possible to extend some chimneys	reduced ground level concentration slight reduction in operating power due to stack effect	visual impact	real reduction in ground level concentration and real reduction in power consumption
	high gas exit temperature	applicable to both new and existing plants	good dispersion hence low ground level concentration	inefficient lime production increase in fuel usage hence increased emissions	negative real benefit as more fuel is used
	air dilution	all sites	low ground level and stack concentrations low CO trip from ESP	increased energy use low stack exit temperature leading to poorer dispersion	in general no net benefit but worth considering for interim air dilution to reduce CO trip
particulate from feed	<i>eliminate</i> wash feed material	applicable to both new and old	less particulate carried over by the flue gas abatement is easier	extra liquid wastes	reduction in dust to the environment
	control of fugitive emissions	all sites  also applicable to feed milling and lime packaging and transport within site	real reduction in particulate emissions  improved overall efficiency of the plant  improved visual impact of site and vicinity	possible energy cost in collecting particulate at transfer points	real environmental benefit in reduction of particulate release to the environment  improved visual impact of site and vicinity  improved efficiency resulting in reduced emissions of NOx, CO, etc
	<i>minimize</i> abatement - ESP - bag filter - gravel bed filter - cyclone	applicable as an end of pipe solution to new and existing sites	minimizes emissions low stack and ground level concentrations	energy penalty performance depends on type of equipment creates landfill problem	dependent on the type of equipment - best option so far is ESP
	<i>render harmless</i> high chimney	applicable to new installation. may be possible to extend some chimneys	reduced ground level concentration slight reduction in operating power due to stack effect	visual impact	real reduction in ground level concentration and real reduction in power consumption

pollutant	method	applicability	advantages	disadvantages	net benefit
particulate from feed	high gas exit temperature	applicable to both new and existing plants	good dispersion hence low ground level concentration	inefficient lime production increase in fuel usage hence increase emissions	negative real benefit as more fuel is used
	air dilution	all sites	low ground level and stack concentrations low CO trip from ESP	increased energy use low stack exit temperature leading to poorer dispersion	In general no net benefit but worth considering for interim air dilution to reduce CO trip
heavy metal from feed	<b>Eliminate</b> select quarry	mainly for new quarries - key is to consider this at the beginning	real environmental benefit and reduction in heavy metal	not always possible	real reduction in heavy metal if achievable
	<b>Minimise</b> blend low metal feed	It may not be available - consider total survey of the quarry and plan quarrying for blending	no real reduction of heavy metal release to the environment over the lifetime of the quarry but averaging of heavy metal emission over lifetime allows environmental recovery  reduces need for abatement - abatement can transfer environmental damage elsewhere  facilitates compliance with limits by giving lower average concentrations emitted	no real disadvantage for the environment but manufacturers may have to have a long term strategic plan also cost of ground survey	helps to achieve low ground and stack concentrations may reduce the need for abatement It will allow the environment to recover local concentration
	Abatement as for particulate and scrubbing for vapour phase metals	applicable as for particulates abatement and scrubber. These are end of pipe solution	reduce stack and ground level concentration  help to meet the limits set	any additional scrubbing will have a energy penalty and hence CO <sub>2</sub> /SO <sub>2</sub> , NO <sub>x</sub> emission to the total environment	abatement as a part of particulate will have benefit, but any additional abatement for heavy metal will have a net environment harm as the concentration are low
	<b>Render Harmless</b> High Chimney	applicable to new installation, may be possible to extend some chimneys	reduced ground level concentration slight reduction in operating power due to stack effect	visual impact	real reduction in ground level concentration and real reduction in power consumption

pollutant	method	applicability	advantages	disadvantages	net benefit
heavy metal from feed	high gas exit temperature	applicable to both new and existing plants	good dispersion hence low ground level concentration	inefficient lime production increase in fuel usage hence increase emissions increase temperature may cause some heavy metal to be in vapour phase and hence will not be in the particulate to be trapped	negative real benefit as more fuel is used
Particulate from fuel mainly for preheat requirement	eliminate use gas, light oil or SLF to reduce requirement for preheat  particulate in fuel to the kiln will have no significant effect to the final kiln exit gas  fugitive coal dust leak	<ul style="list-style-type: none"> <li>- applicable to most sites</li> <li>- availability of gas and the price will be the limiting factor</li> <li>- guaranteed supply will not be available</li> <li>- still require standby fuel and associated issues</li> </ul>	<p>significant reduction from coal or oil fired fuel pre heaters</p> <p>deduction in CO<sub>2</sub>, SO<sub>2</sub>, NOX and particulate</p>	<ul style="list-style-type: none"> <li>- fuel cost</li> <li>- If gas is used explosion hazard</li> <li>- fugitive methane leak</li> </ul>	<p>there is net benefit in reduction of particulate emission from coal fired pre heater stacks</p> <p>reduction in CO<sub>2</sub>/SO<sub>2</sub>/NOX and particulate</p>
	reduce fugitive emission of coal dust from handling	applicable to all sites with coal or pit-coke burning	<p>real reduction in particulate emission visual impact of site and plant</p> <p>fuel efficiency improvement due to reduction in fuel loss</p> <p>reduction in dust explosion risk</p>	none	<p>real improvement particulate emission</p> <p>reduction in explosion risk</p>

pollutant	method	applicability	advantages	disadvantages	net benefit
CO <sub>2</sub> from feed and fuel	<i>eliminate</i> improve plant efficiency by reducing gas exit temperature  use better heat exchanger methods and air pre-heaters	applicable to most processes, theoretically but need to consider each case separately	real reduction in fuel usage and associated emission to the environment	low gas exit temperatures will require greater fan power to transport gas due to the reduction in stack lift  low gas exit temperature will lead to high ground level concentration resulting from lack of dispersion	possibility of net benefit but need to examine it in detail
	<i>minimise</i> abatement techniques	there are abatement techniques available which are not suitable for lime industry particularly considering the quantity of CO <sub>2</sub> producers	reduction in CO <sub>2</sub> emission	not an environmentally friendly option  high energy used, the process is to drive CO <sub>2</sub> away from CaCO <sub>3</sub> , it is not a real option	it is not a practical and environmentally sound idea. Thermodynamic not a sound idea
	<i>render harmless</i>	not applicable for CO <sub>2</sub> as CO <sub>2</sub> has global impact			
SO <sub>2</sub> from fuel	<i>Eliminate</i> use fuel with no sulphur	applicable to all sites	minor improvement in the SO <sub>2</sub> emission	none if it is achievable	if applicable real reduction in SO <sub>2</sub>
	<i>minimise</i> abatement	applicable to all kilns and any fuel pre heaters	reduction in SO <sub>2</sub>	transferring environment problem to elsewhere in the country high electrical power use reduction in gas exit temperature visual impact high CO <sub>2</sub> GLC	no real net benefit to the environment likely harm
	<i>render harmless</i> high chimney	applicable to new installation, may be possible to extend some chimneys	reduced ground level concentration slight reduction in operating power due to stack effect	visual impact	real reduction in ground level concentration and real reduction in power consumption

pollutant	method	applicability	advantages	disadvantages	net benefit
SO <sub>2</sub> from fuel	high gas exit temperature	applicable to both new and existing plants	good dispersion hence low ground level concentration	inefficient lime production increase in fuel usage hence increase emissions inefficient fuel pre heating resulting in increased emission	negative real benefit as more fuel is used
	air dilution	all sites	low ground level and stack concentrations low CO trip from ESP for wet kiln only	increased energy use low stack exit temperature leading to poorer dispersion	In general no net benefit but worth considering for interim air dilution to reduce CO trip for wet kiln only
CO <sub>2</sub> from fuel	<i>eliminate</i> use low carbon fuel natural gas, SF	applicable to all sites, the gas option is difficult as it is not always possible to secure guaranteed supply of gas. The use of SF or similar fuel with low carbon and high H <sub>2</sub> is applicable	- real reduction of CO <sub>2</sub> - benefit in kiln efficiency as these fuel are more controllable than pulverised coal or pet coke real environmental benefit on a global basis if SF can be used	cost implication for gas option	real benefit in considering alternative fuel such as SF on reduction of CO <sub>2</sub> production for town chimney and disposal of SF
	increase plant efficiency	applicable to all plants	real reduction of pollutant of all forms produced for tonne/dm	none	real environmental benefit
	<i>minimize</i> abatement	not applicable			
	<i>render harmless</i>	not applicable			
NO <sub>x</sub> from fuel	<i>eliminate</i> use low Nitrogen fuel	applicable to all kilns	real reduction in NO <sub>x</sub>	cost implication	some benefit but major NO <sub>x</sub> production is from thermal NO <sub>x</sub> from air
	combustion control control excess air	to all kilns	real reduction in NO <sub>x</sub> energy efficiency limit reduced fuel use resulting CO <sub>2</sub> reduction	excessive control could lead to CO trip of the ESPs and kiln instability	real reduction of NO <sub>x</sub> emission

pollutant	method	applicability	advantages	disadvantages	net benefit
NOx from fuel	use fuel with more controllable feature such as gas, light oil or SLF	applicable to most kilns however gas supply will not be guaranteed. Hence alternative fuel will be required	<ul style="list-style-type: none"> <li>- real reduction of NOx</li> <li>- possible kiln efficiency improvement available resulting low CO<sub>2</sub> emission</li> <li>low CO<sub>2</sub> emission from low to carbon fuel</li> </ul>	<ul style="list-style-type: none"> <li>the use of intercept gas supply will result in kiln operation change</li> <li>gas explosion HAZARD</li> <li>fugitive gas leak</li> </ul>	net benefit from controllable fuel natural gas may not be the first option compared to SF and other controllable fuel
	coal milling and fine grinding	applicable for coal fired installation	<ul style="list-style-type: none"> <li>real reduction in NOx production</li> <li>reduced fuel transport lost</li> </ul>	<ul style="list-style-type: none"> <li>high energy cost of milling</li> <li>increased fugitive emission</li> <li>dust explosion hazard</li> </ul>	perceived net benefit but the option needs to be examined in detail likely to result in some benefit
	feed preparation mill feed smaller to get better heat transfer and the need for high flame separation	applicable to all kilns	<ul style="list-style-type: none"> <li>reduction in NOx production</li> <li>improved plant efficiency</li> <li>hence reduce fuel consumption</li> <li>better pre heat transfer</li> </ul>	<ul style="list-style-type: none"> <li>high energy use for milling hence CO<sub>2</sub> emission</li> <li>high particulate emission via stack</li> <li>high fugitive particulate emission</li> <li>low gas exit temperature hence high GLC</li> </ul>	perceived net benefit, but the options need to be examined in detail has potential to reduce NOx emission, as well as CO <sub>2</sub> and SO <sub>2</sub>
	Low NOx burners	applicable to all kilns in general but limited use with coal or pet coke as 25% combustion air is required for fuel transport	<ul style="list-style-type: none"> <li>reduction in NOx production</li> </ul>	<ul style="list-style-type: none"> <li>- longer burning zone with lower temperature</li> <li>- potential to increase dioxin production</li> <li>- if the burning zone is increased it reduces the area/space available for heat transfer to heat feed material hence possible loss in plant efficiency</li> <li>lower temperature will result in poor heat transfer loss in efficiency</li> <li>possible to affect product quality.</li> </ul>	<p>information available claim benefit of NOx reduction. The net environmental benefit is not fully analysed. It is possible that it may not deliver the full benefit</p> <p>this should be considered on a site by site and kiln by kiln basis</p>

pollutant	method	applicability	advantages	disadvantages	net benefit
NOx from fuel	process modification to integrate staged combustion	applicable to all processes additional pre-heating will need to be included together with air control to burn CO	Potential to reduce NOx	It relies on maintaining reducing atmosphere. It will generate high CO in the flue gas which needs to be oxidised downstream.  This will increase the CO trips of the ESPs. Possible CO explosions in the ESP. Additional fans and fuel pumps required. It creates low temperature burning which is conducive to form dioxins.	Net benefit of reducing NOx for the cost of increase CO trips or possible ESP explosions and dioxin formation.  It should be considered and the perceived disadvantages evaluated
	Fuel efficiency	applicable to all kilns	real reduction in NOx production	reduction in gas exit temperature resulting in poor dispersion high GLC of CO <sub>2</sub>	net benefit in NOx for CO <sub>2</sub> formation. Should be considered
	minimise NH <sub>3</sub> injection	applicable to all kilns	reduce stack and GLC of NOx  help to meet the limit	It requires between 2-4 modes of NH <sub>3</sub> to abate 1 mode of NOx for 80% reduction Ref 106  fugitive heat of NH <sub>3</sub> accidental leak and serious harm to public and works.  environmental transport from cost increase CO emission high operating cost Ref 106	It is not a real option with respect to integrated environmental impact as the production of NH <sub>3</sub> by the Haber process starts with N <sub>2</sub> and H <sub>2</sub> which need to be manufactured as well  significant total environmental harm
	wet	applicable to all kilns	reduce stack and ground level concentration of NOx  help meet the limit	It requires absorbing agent which has a manufacturing environmental cost  absorbent such as NH <sub>3</sub> OH require flue gas to be cooled to less than 100°C  visual impact of steam  low flue gas exit temperature lead to GLC increase of CO <sub>2</sub>	no net environmental benefit by applying this technique

pollutant	method	applicability	advantages	disadvantages	net benefit
NOx from fuel	polimtec process	applicable to all kilns	reduce stack and ground level concentration of NOx help meet the limit other reduction SO <sub>2</sub>	again it relies on NH <sub>3</sub> to absorb NOx  this is similar to the problem discussed for NH <sub>3</sub> injection	no net benefit to the total environment as it uses more NH <sub>3</sub> than NOx to absorb NOx
	render harmless high chimney	applicable to new installation, may be possible to extend some chimneys	reduce ground level concentration slight reduction in operating power due to stack effect	visual impact	real reduction in ground level concentration and real reduction in power consumption
	high gas exit temperature	applicable to both new and existing plants	good dispersion hence low ground level concentration	inefficient lime production increase in fuel usage hence increased emissions	negative real benefit as more fuel is used
	air dilution	all sites	low ground level and stack concentrations low CO trip from ESP	increased energy use low stack exit temperature leading to poorer dispersion	in general no net benefit but worth considering for interim air dilution to reduce CO trip
heavy metal from fuel	eliminate useful with low or no heavy metal	applicable to all kilns providing the alternative fuel can be obtained cost effectively  only gas and high oil loss no tar or low metal content metal content in SF can be controlled	perceived reduction of metal emission	reduction in choice of fuel	the metal emission is mainly from feed and kiln lining
	minimise abatement as part of particulate abatement	applicable for most kilns as part of their particulate abatement	reduction in stack and ground level concentration	energy and the associated CO <sub>2</sub> lost	real benefit as and if it is part of the particulate abatement  other form of bespoke abatement are not environmentally efficient for the volume of gases and the very low quantity of emission



pollutant	method	applicability	advantages	disadvantages	net benefit
heavy metal from fuel	bespoke metal abatement leaks for small scale gas clean ups	not applicable for lime works			
Dioxins	<i>eliminate</i> eliminate Cl <sub>2</sub> and aromatic hydrocarbon in fuel	applicable to most kilns providing gas is available	perceived reduction in Dioxin most dioxins formed in kilns are from feed	elimination of suitable fuel from users in the kiln	type of fuel does not change the dioxin emission from the kiln significantly the errors in measurement of dioxin in the flue gas is orders of magnitude greater than any possible change due to fuel this is an inefficient use of effort to control dioxin release
	<i>minimise</i> carbon filter and other abatement	applicable as part of the general abatement	perceived reduction in dioxin release from kilns help to project a good image	introduce general inefficiency in clinker production as the need to operate the abatement equipment	no real benefit in reduction in dioxin release since the errors in measurement are in general greater than any contribution from choice of level
	<i>render harmless</i> high chimney	applicable to new installation, may be possible to extend some chimneys	reduced ground level concentration slight reduction in operating power due to stack effect	visual impact	real reduction in ground level concentration and real reduction in power consumption
	high gas exit temperature	applicable to both new and existing plants	good dispersion hence low ground level concentration	inefficient lime production increase in fuel usage hence increased emissions	negative real benefit as more fuel is used
	air dilution	all sites	low ground level and stack concentrations low CO trip from ESP	increased energy use low stack exit temperature leading to poorer dispersion	In general no net benefit but worth considering for interim air dilution to reduce CO trip