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The use of substitute fuels in the UK cement and lime industries

Science Report: SCO30168

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Steve Killeen

Head of Science

Executive summary

This report reviewed the use of substitute fuels (SFs), such as tyres, secondary liquid fuel and waste derived biofuels, in the UK cement and lime industries. The main purpose of this review was to develop a better understanding of the use of SFs in cement and lime kilns and their environmental impact.

An overview of the cement and lime industries in the UK is included, together with the regulatory requirements and non-regulatory agreements for these industries. The types of SF used were reviewed, with the substitution rate for SFs in the UK (14 per cent in 2005) found to be below the average figure for Europe (17 per cent in 2004).

In the UK, 13 cement plants have trialled or are using SFs. Two lime plants are also using substitute fuels.

An overview of regulatory requirements and non-regulatory agreements relating to the use of SFs is also provided, along with a review of compliance for cement works using SFs. The Environment Agency's Compliance Classification Scheme shows that there were no Category 1 incidents (non-compliance that caused or had the potential to cause major extensive harm) and only one Category 2 incident (non-compliance that caused or had the potential to cause significant localised environmental harm) relating to cement works in 2005. This latter incident was not related to the use of SFs.

The report also provides an overview of consultation comments in response to applications for SFs. No preventions of SF use for environmental, planning or other reasons were identified in the review. The Environment Agency received more comments regarding applications to burn SFs from non-statutory consultees than statutory ones. The majority of comments could be divided into the following groups: environmental impacts; public health concerns; possible odour nuisance; effects on food chain; safety issues; and general issues.

Environmental studies of alternative uses for SFs were reviewed here, including ambient monitoring of NOx and SO2, and public health concerns over air quality, odour nuisance, possible effects on food chain and safety issues.

This project analysed the effects of burning SFs in cement and lime kilns, including the effects on cement-making operations. The analysis showed that in relation to the burning of a single SF, the burning of secondary liquid fuel, Cemfuel®, tyres and refuse-derived fuel could help reduce the total impact of air emissions.

All cement and lime kilns that use substitute fuels, designated as wastes, must comply with the requirements of the Waste Incineration Directive (WID) for co-incineration plants. The WID introduces additional monitoring requirements and strict emission limits for a range of pollutants. Our review found that most operators using SFs installed selective non-catalytic reduction (SNCR) in order to meet WID limits for nitrogen oxides. Similarly, some operators had to improve their abatement of particulate matter from kiln stacks to meet the 30 mg N m-3 WID limit for these emissions. Accordingly, the use of SFs as per WID guidelines has helped reduce emissions of these pollutants at many installations.

An impact assessment considered air quality, health risk assessment (HRA), odour, greenhouse gases (GHGs), energy efficiency and waste arising from SF burning in cement kilns. Emissions data, assessments (using Environment Agency methodology), ambient monitoring data and dispersion modelling results were reviewed to address air quality. The report concludes that long-term and short-term pollutant concentrations

arising from cement kilns are small fractions of air quality strategy objectives, irrespective of whether conventional fuels or SFs are burnt. Odour has so far not been an issue for SF usage. Emissions of GHGs, principally CO2, were calculated for a pre-heater kiln and showed that the use of biofuels (meat and bone meal, processed sewage pellets and refuse-derived fuel) reduces CO2 emissions. Generally, the use of SFs does not produce more waste.

Information from HRAs, health impact assessments and other studies was reviewed to help determine our HRA. Under normal operation, there would be a negligible risk to human health from the use of any of the SFs.

The burning of SFs in cement and lime kilns is currently subject to the Substitute Fuels Protocol (SFP). The procedure takes the operator from the initial consultation stages through to the outcome of the SF commissioning trial.

Best practice in this area encompasses all regulatory, environmental, technical and commercial issues including technical design and operational requirements of the plant. Economic issues are obviously of great importance to cement and lime plant operators, but these details are commercially sensitive and hence are not available in the public domain.

Contents

List of Tables

List of Figures

1 Introduction

1.1 Study Background

In July 2005, the Environment Agency commissioned Atkins to produce a review of the use of substitute fuels (SFs) in cement and lime kilns in the United Kingdom (UK).

The purpose of the review was:

- to improve our knowledge of the use of SFs in UK cement and lime kilns, including environmental and regulatory issues associated with their use;
- to better understand the environmental impact of SFs, which would help to reduce the complexity and time required to obtain a permit to use SFs in cement and lime kilns;
- to identify best practice in the application, determination and regulation of any permits allowing their use;
- to review briefly the economic aspects and impacts of using SFs on the cement-making process and the technologies employed to burn SFs.

1.2 Specific Objectives

The study required the following tasks to be undertaken:

- using expert knowledge and previously compiled reports, identify all SFs used in UK cement and lime kilns;
- identify any SFs with the potential to be used in the UK, based upon UK, European or world experience;
- collate all available data on emissions to air from cement and lime kilns with and without the use of SFs;
- characterise all SF usage at point of use, including chemical and physical characteristics and quantities used;
- describe the means of delivery, storage and handling of SFs up to and including the combustion stage;
- review any health assessment work based on cement works burning SF;

- review compliance records of kilns burning SF;
- comment on the composition of SFs and the process of SF production;
- investigate other uses of SFs and compare with their use in cement kilns;
- investigate how the use of SFs ties in with Waste Incineration Directive (WID) requirements;
- review local air quality monitoring data around installations burning SFs;
- investigate the nature and extent of consultation comments when applications to use SFs have been made;
- identify where the use of SFs has been prevented by environmental, planning or other legislative reasons;
- investigate the impacts of SFs other than on air emissions.

1.3 Methodology

The methodology for this study was divided into the following three stages:

- information gathering, which was completed in June 2006;
- data analysis;
- review and assessment of data.

Annex A provides further information on the methodology for the study.

2 UK cement and lime industries and use of substitute fuels.

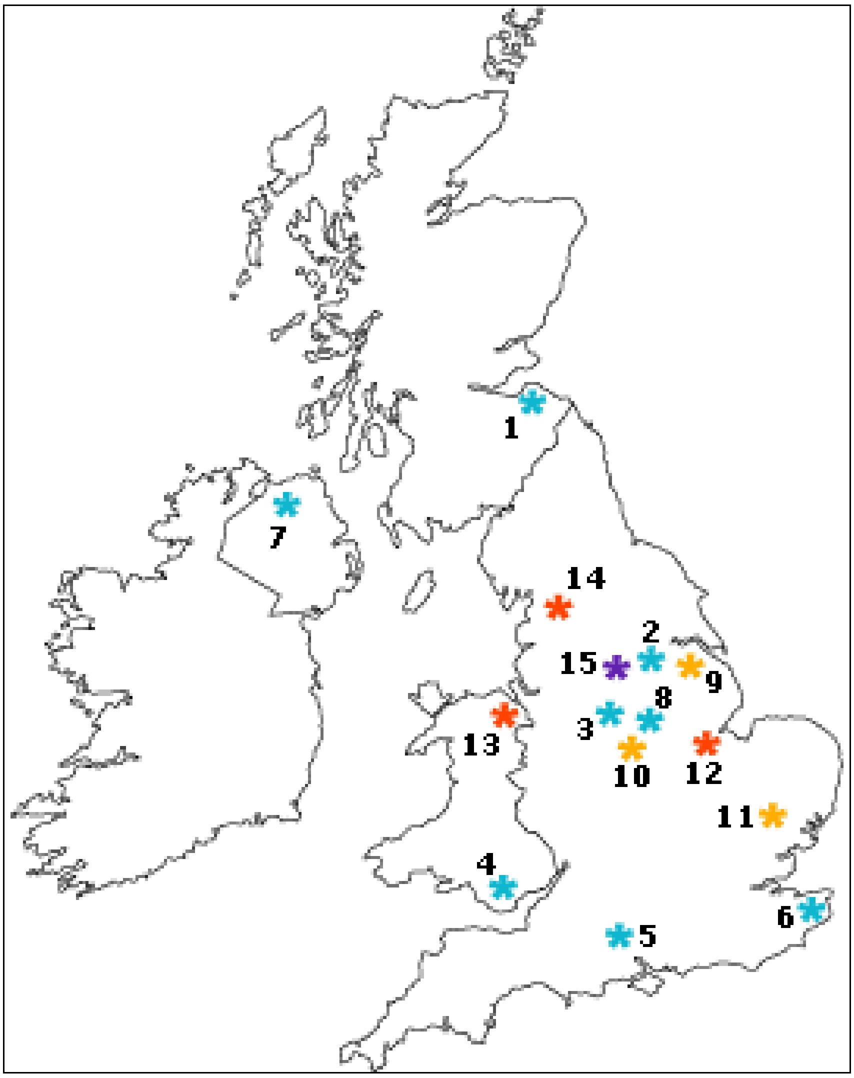
This section provides an overview of the following:

- cement and lime industries in the UK;
- regulatory requirements and non-regulatory agreements for these industries;
- types of SF used in these industries;
- regulatory requirements and non-regulatory agreements on the use of SFs;
- review of compliance for cement works using SFs;
- nature and extent of consultation comments in response to applications to use SFs;
- identification of where the use of SFs has been prevented by environmental, planning or other legislative reasons;
- delivery, storage and handling of SFs;
- alternative uses of materials used as SFs.

2.1 Overview of cement and lime industries in the UK

The locations of 15 cement plants in the UK are shown in Figure 2.1. The major companies involved in cement plant operation include Lafarge Cement UK (LCUK), part of the Lafarge Group, which operates eight cement plants (although the Barnstone works no longer produces clinker and is used as a grinding plant only for special cements). Cemex UK Cement operates three cement plants and Castle Cement, part of the Heidelberg Cement Group, also operates three plants. Tarmac Ltd, Buxton Lime & Cement operates one plant.

Figure 2.1: Map showing the location of UK cement plants



	Lafarge Cement		**Cemex UK Cement**
1	Dunbar	9	South Ferriby
2	Hope	10	Rugby
3	Cauldon	11	Barrington
4	Aberthaw		
5	Westbury		**Castle Cement**
6	Northfleet	12	Ketton
7	Cookstown	13	Padeswood
8	Barnstone	14	Ribblesdale
			Tarmac Ltd, Buxton Lime & Cement
		15	Tunstead

Source: British Cement Association website

Table 2.1 provides the British Cement Association (BCA) published data on UK cement plant capacity.

Table 2.1: British Cement Association published data on UK cement plant capacity

Company	Number of sites	Production capacity 2004 tonnes/year cement
Tarmac Ltd, Buxton Lime & Cement	1	750,000
Castle Cement	3	3,100,000
LCUK	6	4,945,000
Cemex	3	2,250,000
Total	13	11,045,000

An overview of the operation of cement plants in the UK producing clinker is provided in Table 2.2.

Table 2.2: Overview of operation of cement plants in UK producing clinker

Information	**Description**
Dunbar works	
Technology	One mid-1980s air separate (AS) pre-calciner suspension pre-heater (SP5) kiln of 3,300 tonnes/day output with grate clinker cooler
Date of installation	1985
Cement capacity	Around 1,000,000 tonnes/year
Pollution control	Electrostatic precipitator (ESP) for kiln and raw mill de-dusting
Special process features	A new wet scrubber is being installed to reduce sulphur dioxide (SO_2) emissions
Hope works	
Technology	Two pre-heater SP4 kilns originally started in 1970 which were modernised in the late 1990s with new low pressure (LP) cyclones and enlarged riser ducts
Date of installation	Construction 1968, Kilns 1 and 2 commissioned 1970
Cement capacity	Around 1,300,000 tonnes/year
Pollution control	Baghouses for kiln and raw mill de-dusting, cooler exhaust gases cleaned by ESPs, and the use of selective non-catalytic reduction (SNCR) for NO_x reduction.
Special process features	Both kilns have been modernised with larger riser ducts and two modern baghouses have been fitted

Information	Description
Cauldon works	
Technology	One pre-calciner AS-SP4 kiln process from the mid-1980s with a grate clinker cooler One mid-1980s air separate (AS) pre-calciner suspension pre-heater (SP5) kiln of 3,300 tonnes/day output with grate clinker cooler.
Date of installation	1985
Cement capacity	Around 1,000,000 tonnes/year
Pollution control	ESP for kiln and raw mill gases, SNCR for NO_x reduction and a new baghouse for the cooler unit which replaced the original gravel bed filter (GBF) unit
Aberthaw works	
Technology	One pre-heater kiln process (SP4) with some riser duct firing and planetary clinker cooler
Date of installation	1976
Cement capacity	Around 500,000 tonnes/year
Pollution control	Original 1970s design ESP for kiln and raw mill de-dusting was recently replaced by a new baghouse and use of selective non-catalytic reduction (SNCR) for nitrogen oxides (NO_x) reduction.
Westbury works	
Technology	Two wet process kilns of 1960s design with grate clinker coolers
Date of installation	1962 and 1969
Cement capacity	Around 728,000 tonnes/year
Pollution control	The original ESPs for kiln gases were replaced by newer units some years ago; the cooler exhaust uses older technology GBF units
Northfleet works	
Technology	Two kilns which were converted to semi-wet operation in 1993 with slurry being treated by filter presses; plant is due to close in 2007
Date of installation	1970
Cement capacity	Around 1,200,000 tonnes/year
Pollution control	ESP for kiln and cooler exhaust gases
Cookstown works	
Technology	One Lepol kiln process from 1960s
Date of installation	Commissioned 1968
Cement capacity	Around 500,000 tonnes/year
Pollution control	Original ESP for Lepol kiln exhaust gases, whilst the cooler and Aerofall raw mill exhaust gases are de-dusted via a modern baghouse

Information	Description
South Ferriby works	
Technology	Two Lepol process kilns (Kilns 2 and 3) with grate type clinker coolers
Date of installation	Kiln 2 started operation in 1968 and Kiln 3 started operation in 1974
Cement capacity	Around 700,000 tonnes/year
Pollution control	ESP for kiln and raw mill de-dusting
Rugby works	
Technology	One SP2 pre-calciner kiln with combustion chamber and a grate type clinker cooler
Date of installation	2000
Cement capacity	Around 1.3 million tonnes/year
Pollution control	Original ESP for main kiln stream replaced in 2007 with bag filter. Raw mill and fuel mill have bag filters. Clinker cooler and kiln bypass have ESPs.
Special process features	Design uses a crusher dryer instead of a conventional vertical spindle mill (VSM) raw mill; SO_2 reduction is achieved by injecting the clay into the pre-calciner vessel where the high free lime atmosphere helps absorb the SO_2; chalk slurry feed is pumped via a 92 km pipeline from Kensworth quarry
Barrington works	
Technology	One wet kiln process with planetary clinker cooler
Date of installation	1964
Cement capacity	Around 300,000 tonnes/year
Pollution control	Original ESP for kiln has undergone some modernisation
Ketton works	
Technology	Two kilns; Kiln 7 is a 1,450 tonnes/day pre-heater kiln (SP4) with planetary coolers which was modernised in 1996; Kiln 8 is an SP4 AS pre-calciner kiln (3,400 tonnes/day) with a grate type clinker cooler
Date of installation	Kiln 7 1975, Kiln 8 1986
Cement capacity	Around 1,400,000 tonnes/year
Pollution control	ESPs used for kiln and raw mill de-dusting with both kilns, Kiln 8 also has an ESP for cooler exhaust gases
Special process features	Kiln 7 was built with a kiln bypass system which was modified during the upgrading to reduce dust losses; Kiln 8 will have a new kiln bypass installed

Information	Description
Padeswood works	
Technology	One modern SP5 pre-calciner kiln with separate line calciner-downdraft (SLC-D) type (F L Smidth (FLS)) calciner and a grate type clinker cooler
Date of installation	Commissioned 2005
Cement capacity	Around 800,000 tonnes/year
Pollution control	Modern baghouse, a short trial with SNCR is planned
Special process features	SLC-D calciner uses shale as both a raw material and fuel input, with the shale being fired in the pre-calciner to make use of its calorific value (CV) and to minimise potential volatile organic compound (VOC) emissions; kiln bypass design uses an ESP with exhaust gases recycled to the pre-calciner vessel to reduce heat loss
Ribblesdale works	
Technology	One 1982 FLS designed SP4 in line calciner (ILC) pre-calciner kiln with a grate type clinker cooler
Date of installation	Kiln 7 1982
Cement capacity	Around 750,000 tonnes/year after the closure of the two wet process kilns (Kilns 5 and 6)
Pollution control	ESP for kiln and raw mill de-dusting
Special process features	An SO_2 scrubber was installed during the 1990s using cooler exhaust gases for reheating the stack gases
Tunstead works	
Technology	One modern SP4 pre-calciner kiln process with multi-stage combustion (MSC) and a grate type clinker cooler
Date of installation	Construction started 2000
Cement capacity	Around 800,000 tonnes/year
Pollution control	Three modern baghouses are used for kiln, raw mill, cooler and coal mill exhaust gas de-dusting
Special design features	Standard FLS ILC pre-calciner process used with MSC for NO_x reduction, four cyclone stages used to provide sufficient quality of heat for drying the feed, which includes some slurried raw material

The use of SFs in the UK lime industry is restricted to Thrislington and Whitwell Lime works, both operated by Steetley Dolomite Ltd (SDL). The Thrislington works produces 350,000 tonnes/year of dolomitic lime for the steel, chemical, brick and block industries. There are two operational kilns at the works, one of which is a conventional rotary kiln dating from 1956 and the other, a rotary kiln dating from 1978 with a grate pre-heater. The plant uses ESP dust arrestment equipment. The Whitwell lime works produces 250,000 tonnes/year of dolomitic lime for the steel, chemical, ceramic, cement, and brick and block industries. There are two rotary kilns at the works, one of which was installed in 1960 and the other in 1972. The plant uses ESP dust arrestment equipment.

2.2 Regulatory Requirements and non-regulatory agreements for Cement and Lime Industries

2.2.1 Pollution Prevention and Control

Cement and lime kilns are regulated under the pollution prevention and control (PPC) regime which was introduced by the Pollution Prevention and Control Regulations (England and Wales). The PPC permit granted for an installation must include conditions for the installation's operation where all preventative measures are taken against pollution, and no significant pollution is produced. These conditions must also ensure that other requirements of PPC Regulations and other legislation are taken into account. Permits are issued and enforced by the Environment Agency (England and Wales), the Scottish Environmental Protection Agency (Scotland) and Department of the Environment for Northern Ireland (Northern Ireland). More information on PPC requirements is provided in the Department for Environment, Food and Rural Affairs (Defra) guide on Integrated Pollution Prevention and Control[1].

A primary consideration in setting conditions in the permit is the use of best available techniques (BAT) for the particular installation. These balance costs to the operator against benefits to the environment in seeking to prevent, and where this is not practicable, generally to reduce emissions and the impact on the environment as a whole. The technical guidance note for the cement and lime sector provides information on indicative BAT for the sector, which sets the minimum requirements. Where indicative BAT is not being used at the installation, improvement conditions will be set which require the operator to introduce environmental improvements as soon as practicable. Where the environmental setting of the installation is such that indicative BAT would not be adequate to reduce emissions and the impact on the environment to an acceptable level, site-specific BAT will be determined.

Cement and lime kilns burning SFs also have to comply with the requirements of the WID, which are discussed later in this section.

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[1] Defra. *Integrated Pollution Prevention and Control: A Practical Guide*. 2005.

2.2.2 Sector Plan

The Environment Agency has produced a sector plan for the cement industry with objectives to further improve the sector's environmental performance. The plan has been produced jointly with the industry, and forms a framework of agreed national environmental objectives and priorities for the cement industry over the next five to 10 years. The plan includes an overview of the salient environmental and economic issues for the sector and comprises a set of high level objectives and indicators of performance, covering both statutory and non-statutory activity. Key environmental issues associated with cement production include resource extraction (fuel and raw materials), particulate emissions, gaseous air pollutants (in particular NOx, SO2 and CO2) and generation of waste. The plan's principal objectives are as follows:

- to reduce the consumption of natural resources per tonne of cement manufactured;
- to reduce the amount of cement process waste residues disposed of per tonne of cement manufactured;
- to reduce pollution from cement manufacturing;
- to reduce emissions of greenhouse gases (GHGs) per tonne of cement manufactured;
- to optimise the sustainable use of wastes from other industries or sources;
- to develop site restoration plans and biodiversity action plans;
- to improve transparency, understanding and engagement between the Environment Agency, industry and other affected groups;
- to work on risk-based regulatory and environmental management systems;
- to promote product stewardship and wider supply chain benefits.

The plan states that the cement industry has for a long time been pursuing the use of waste materials as a substitute for conventional raw materials and fuels in the manufacturing process. The environmental benefits of this include a reduction in the use of natural resources, beneficial use of waste and minimisation of national CO2 emissions. In addition, the use of these materials can reduce air emissions of other pollutants, principally NOx. The plan also states that the burning of waste-derived SFs in cement kilns will only be allowed where they cannot be technically and economically recovered or recycled further up the waste hierarchy. In the longer term, the availability of suitable waste streams and the development of alternative options higher up the waste hierarchy may set an optimum level of fuel substitution. Targets set for the use of wastes over the five-year period of the plan are based on current projected levels of availability of wastes.

2.2.3 European Union Emissions Trading Scheme

The Framework Convention on Climate Change requires developed countries to take measures to return emissions of GHGs, in particular CO2, to 1990 levels by 2000 and to provide assistance to developing countries. Under the Kyoto Protocol, parties to the climate change treaty agreed to make legally binding cuts in the emissions of six GHGs including CO2. Between 2008 and 2012, developed countries are to reduce their emissions by an average of 5.2 per cent below 1990 levels. The target for the European Union (EU) is eight per cent, with the target for the UK being 12.5 per cent. The protocol also permits emissions trading, from 2008, between countries as a means of meeting targets and countries may also use 'carbon sinks' (activities which absorb carbon from the atmosphere) to meet targets.

In July 2003, the EU adopted a directive establishing a scheme for greenhouse gas emissions allowance trading, called the EU Emissions Trading Scheme (ETS). This has been implemented in the UK through the Greenhouse Gas Emissions Trading Scheme Regulations. The scheme initially applies to major industrial and power installations and only covers CO2. Installations must have a GHG permit and are allocated a GHG quota enabling the holder to emit a specified amount of GHGs. Allowances are transferable and there is a penalty for exceeding a quota. A further directive enables participants to use 'emission credits' from projects to reduce GHG emissions or the transfer of clean technologies to developing countries and those in transition to meet their annual emission targets. Between 2005 and 2007, 95 per cent of permits for emission quotas will be allocated free of charge, lowering to 90 per cent in 2008 to 2012, with the remainder being auctioned.

During 2005 to 2007, Member States may request an exemption for companies or sectors from the EU scheme, providing the companies are achieving similar CO2 reductions through national schemes. From 2008 to 2012, the scheme will be binding for relevant sectors.

The UK Government is aiming to cut CO2 emissions by 60 per cent, based on current levels, by 2050. Central to the achievement of this target is the introduction of a carbon emissions trading scheme, established in 2002. The scheme is voluntary and continues until 2007. Exceedance of an allowance will result in both a financial penalty and the following year's allowance being reduced by the amount of the exceedance. Under the GHG regulations mentioned above, emissions of CO2 from listed activities are controlled and installations carrying out such activities were required to apply for a permit before 31 January 2004 to ensure that the permit was issued by 31 March 2004. The web-based Emissions Trading Registry was established in the UK at the end of May 2005.

2.3 Types of substitute fuel used in the cement and lime industries

An SF is any material for use as a fuel in cement and lime manufacturing which replaces conventional fuel such as coal, petroleum coke, natural gas or oil. In order for a material to be used as a SF, it must not be possible for the SF to be technically and economically recovered or recycled further up the waste hierarchy. The SF must be of consistent quality in order to avoid kiln instability and be available in sufficient quantity to justify the capital investment required for a new SF handling and firing system and the costs associated with permitting the use of the SF. It is advantageous for a SF to have a high calorific value (CV), since it is replacing the fuel in the manufacturing process. In certain cases, the SF can replace raw materials as well as the fuel − a further advantage.

The cement-making process and cement quality parameters are sensitive to components such as chloride, sulphur, alkalis and phosphorus pentoxide (P2O5). Therefore, the contents of these parameters is an important factor which may limit the percentage thermal substitution possible with the SF or, in extreme cases, make the material unsuitable for use as a SF.

The main categories of SF currently used in the UK cement and lime industries can be broadly classified as follows:

- secondary liquid fuel (SLF) such as Cemfuel®, recovered fuel oil (RFO) and recycled liquid fuel (RLF);
- tyres, whole or chipped;
- solid recovered fuels (SRF) such as refuse-derived fuel (RDF), Profuel® and Climafuel®;
- biofuels such as meat and bone meal (MBM) (also called agricultural waste-derived fuel (AWDF)) and processed sewage pellets (PSP).
- Secondary liquid fuel

Cemfuel®, which is a SLF, is produced by Solvent Resource Management (SRM), a member of the Heidelberg Cement Group. Cemfuel® is manufactured from residues from recycling clean solvent from waste for re-use in industry and from waste solvents and hydrocarbons that cannot be recycled. Wastes are generated during the production of household products including paints, inks, adhesives, plastics, and automotive fluids, cleaning solvents and varnishes.

Most used or discarded oil from automotive, shipping and industrial lubrication applications is recovered and made into a fuel called RFO. Historically, RFO has found use in a number of industrial applications as an alternative hydrocarbon fuel to virgin fossil fuels such as oil or gas. RFO is similar in composition and physical properties to the diesel light-up fuel used in the cement industry.

RLF is made from non-recoverable materials used in making products such as screen wash, paint, printing ink and brush cleaners.

2.3.1 Tyres

Tyres, which are used as an SF either whole or chipped, have the same high CV as coal. In addition, the steel reinforcing oxidises in the cement kiln and replaces a portion of the iron that would otherwise be added to the raw material mix used in cement manufacturing. Sapphire Energy Recovery (SER) is a joint venture between LCUK and Michelin tyres, which now processes over 100,000 tyres each year for use as a fuel in cement kilns. This constitutes approximately 20 per cent of used tyres in the UK.

2.3.2 Refuse-derived fuel

RDF covers a wide range of waste materials (residues from municipal solid waste (MSW) recycling, industrial/trade waste, sewage sludge, biomass waste, and so on) which have been processed to fulfil guideline, regulatory or industry specifications mainly to achieve a high CV. The fraction of MSW used to produce RDF is generally the non-recyclable residue left after pre-treatment of the waste. The term 'refuse-derived fuel' in English-speaking countries usually refers to the segregated high CV fraction of processed MSW. Other terms may be used for MSW-derived fuels such as recovered fuel (REF), packaging-derived fuel (PDF), paper and plastic fraction (PPF) and processed engineered fuel (PEF). More recently, with the introduction of mechanical biological treatment (MBT) plants to recover MSW, the term solid recovered fuel (SRF) is being used to describe the residue from these plants.

CEN/TC 343 has been established to develop European standards for the market for solid recovered fuels. Its scope is "elaboration of standards, technical specifications and technical reports on solid recovered fuels (RDF, etc) made from non-hazardous combustible waste to be utilised for energy recovery in waste incineration or co-incineration plants, excluding those fuels which are included in the scope of CEN/TC 335." Standardisation is based on Mandate M/325 from the European Commission, partly in support of the RES-E Directive 2001/77/EC.

The business plan of CEN/TC 343 Solid Recovered Fuels Committee states the following, regarding the business environment, benefits and priorities.

- Business environment

- European standardisation of solid recovered fuels is seen as a key to increase the safe and efficient use of solid recovered fuels and for their acceptability in the fuel market in Europe. The total production of solid recovered fuel forecast for 2005, 10 million tonnes per year (five million tonnes oil equivalent), represents a substitution rate of four per cent of the amount of hard coal used for power production in the EU.

- Classified solid recovered fuels can be used for the substitution of fossil fuels in many sectors, for the production of heat and/or power and in different industrial furnaces. Different technologies for solid fuel combustion such as grate firing, fluidized bed firing, pulverized fuel firing and gasification can be used.

- Parties involved are material producers, waste management companies, producers of heat and/or power, producers of lime and cement clinker, equipment producers and trade associations, authorities and NGOs.

2.3.3 Benefits

- less dependency on imported fuels (security of supply);
- increased public trust in and acceptance of solid recovered fuels;
- common procedures and free trade on the internal market;
- measurement of "biodegradable content" in support of the RES-E Directive;
- creation of jobs in an expanding industry;
- increased recovery and less final disposal of combustible non-hazardous wastes.

2.3.4 Priorities

The most important drafted technical specifications have passed internal enquiry and all specifications were submitted for publication to CEN/CMC by 3 September 2005.

Validation of sampling methods and testing procedures will take place before the process of upgrading to ENs begins.

The development of an overall quality management system is a major element.

Profuel® is produced by SRM and is manufactured to a detailed specification. It used to be made solely from paper, plastic and fibre wastes from all types of manufacturing processes. At this time, the fuel was derived from materials that could not be recycled such as dry organic waste from the printing and packaging industries, low chlorine plastics and off-cuts from the production of carpets, nappies and crisp packets. Waste materials suitable for Profuel® come principally from the following industries: automotive; carpet; construction products packaging; food and drink packaging; furniture; general plastics and plastic film; hygiene products; nappies; paper; photographic; pressure sensitive materials; roll labels; and wallpaper. More recently, RDF and SRF have been used to produce Profuel®. Currently, the composition of Profuel® varies depending on the wastes used for its production, which is determined by the availability of wastes. Profuel® has a similar CV to coal.

The variation BJ1281 to the PPC permit for the Ketton works includes the following materials which are authorised for use in Profuel®:

- ‘tailings’ from the manufacture of infant care products;
- acetate, films and paper from photographic chemical recovery process;
- cement sacks (new and used);
- paper and cardboard packaging waste from all Castle Cement premises;
- off-cuts and redundant stock from greeting card manufacture;
- fluff and trimmings from carpet manufacture;
- medium density fibreboard (MDF) off-cuts from manufacturing processes.

Climafuel® also used to be made solely from packaging waste, but more recently RDF and SRF have been used in its production. A typical analysis for Climafuel is shown below.

Table 2.3: Typical Climafuel analysis

Component	Maximum concentration in batch
S	1% w/w
Cl	1.5% w/w
F	0.5% w/w
Br	0.25% w/w
I	0.25% w/w
Heavy metals (mg/kg)	
Group 1 Hg	10
Group 2 Cd Tl Total Cd and Tl	 20 20 30
Group 3	
Total of all Group 3 HMs	800
An	150
As	00
Cr	150
Co	75
Cu	500
Pb	200
Mn	150
Ni	150
Vn	100
Others (mg/kg)	
PCB	10

2.3.5 Biofuel

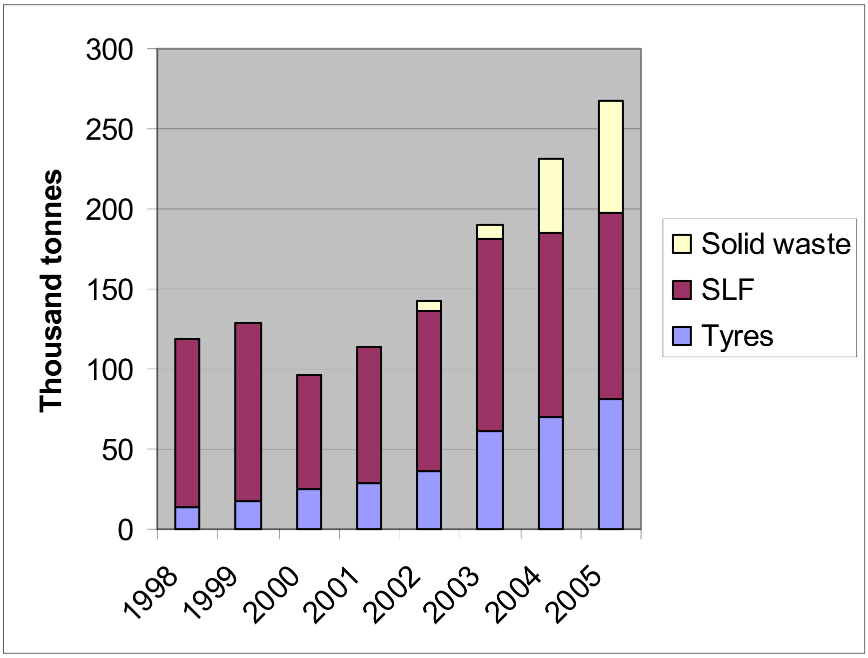
The biofuel MBM is derived from waste from the preparation of meat for human consumption. Materials that go into MBM have been subjected to a rigorous regulatory testing procedure to ensure they do not contain transmissible spongiform encephalopathy (TSE). The waste is rendered, a process which involves cooking and grinding at rendering plants. This high temperature process (150-160ºC for approximately 40 minutes) is essentially a series of moisture and fat reduction steps, which transform the waste into a mixture of solid and fibrous animal material and liquid tallow. The liquid is drained off and the remaining material is pressed dry and milled to produce MBM as a granular solid material. The yield of MBM is about 28 per cent of the original weight of animal by-product processed. Physically, MBM is a meal-like substance with a fat content of about 14 per cent and moisture levels of two to 10 per cent.

PSP is made from the sludge that remains after sewage treatment by drying and heat treatment.

2.3.6 Current substitute fuel use in UK cement industry

The use of SFs by the UK cement industry in 2005 was reported as 267,000 tonnes per year. The historical use of waste as SFs is shown in Figure 2.2. The data for 1998 to 2003 are provided in the Environment Agency's sector report for the cement industry[2], whilst those for 2004 and 2005 were obtained from the British Cement Association (BCA).

Figure 2.2: Waste used as fuel in cement kilns



[2] Environment Agency. *Measuring environmental performance - Sector report for the cement industry*. 2005. This document is available from the Environment Agency website.

Recently, the BCA updated these figures to include a more detailed breakdown of the tonnage of SFs used. These data are summarised in Table 2.4 and show the growth in SF use from 1990, when SF was limited to tyres. Thermal substitution rates reported by the BCA are as follows: 11.5 per cent in 2004 and 14.3 per cent in 2005.

Table 2.4: Historical tonnage of SF used in the UK cement industry

SF	1990	2000	2001	2002	2003	2004	2005
Waste oils	0	5,160	4.540	2,520	720	600	452
Waste solvents	0	77,642	89,128	118,589	92,710	114,607	116,747
Tyres	600	32,178	36,614	45,741	67,483	65,587	81,133
Paper/plastic mix including Profuel® (part biofuel)	0	550	0	8,200	24,415	31,228	34,307
Sludges: paper and sewage (100% biofuel)	0	0	0	840	11,050	14,290	20,348
MBM (100% biofuel)	0	0	0	0	0	1,000	15,364
Total	600	115,530	130,282	175,890	196,378	227,312	268,351

Actual SF tonnage used is usually less than the maximum specified in PPC permits. This is because operators obtain permission for the maximum feasible rate of SF use, to allow them the greatest flexibility of operation. Therefore, the maximum feasible rate of SF use is employed in the trials carried out by operators as part of the permitting process. In reality, there may be constraints on SF availability or feed system reliability, which result in a lower actual use.

2.3.7 Future use of substitute fuels in UK cement industry

Table 2.5 summarises the tonnes of SF permitted to be burned (or permitted subject to a successful commissioning trial). It also includes applications to burn SFs that have not yet been permitted, as well as proposed SF use for which a formal application has not yet been submitted to the regulator.

Table 2.5 shows that the total tonnage of SFs listed in PPC permits is around 1,050,000 tonnes per year, of which 370,500 is permitted subject to successful trials. In addition, 35,050 tonnes of SFs are included in PPC applications. The cement capacity listed in Table 2.5 does not include the Northfleet works (capacity of 1.2 million tonnes/year cement) and Barnstone works (capacity up to 100,000 tonnes/year special cements) or the Rochester grinding plant (capacity around 650,000 tonnes/year cement), because these works do not burn SFs and have no plans to do so within their remaining operational life.

Table 2.5: Cement plants using or trialling SFs in the UK

Cement works	Annual cement production	Operator	SLF		Tyres chips or whole	RDF		Biofuels	
	Kilotonnes		RFO	Other		Profuel®	Climafuel®	MBM	PSP
Aberthaw	500	LCUK	Applied for (30%)[1,2]					Trials in progress[3] (30%)[1] 20,000[4]	
Barrington	300	Cemex	SLF (40%)[1] 65,000[5] Oil/Oily water 50[6]				(30%)[1] 35,000[6]		
Cauldon	1,000	LCUK	Applied for[2]		(40%)[1] 50,000[5]				(45%)[1] 70,000[5]
Cookstown	500	LCUK	(40%)[1,9]		(12%)[1,8]				
Dunbar	1,000	LCUK	(40%)[1] 30,000[5]		(25%)[1] 31,5005				
Hope Kilns 1+2 total	1,300	LCUK	Applied for[2]		(20%)1 35,0005			(30%)[1] 70,000[4]	
Ketton Kiln 7		Castle		(40%)[1]	(25%)[1] 40,000[5]	(40%)[1]		(40%)[1]	
Ketton Kiln 8		Castle		(25%)[1]		(50%)[1]		(50%)[1]	
Ketton (Kilns 7+ 8)	1,400	Castle		73,500[5]	40,000[5] (Kiln7)	80,000[5]		55,000[4]	

Cement works	Annual cement production	Operator	SLF		Tyres chips or whole	RDF		Biofuels	
	Kilotonnes		RFO	Other		Profuel®	Climafuel®	MBM	PSP
Padeswood	800	Castle		(40%)[1] 69,000[4]	(25%)[1] 25,000[4]	(75%-calciner) [1] (20% kiln) [1] 108,000[4]			
Ribblesdale	750	Castle		(40%)[1] 45,500[5]	(25%)[1] 40,000[5]			(50%)[1] 55,000[5]	
Rugby	1,350	Cemex			(10%)[1,10] 23,500[4,11] Trials completed[2,12]				
South Ferriby (Kilns 2 + 3)	700	Cemex	(40%)[1] 20,000[5]		Trial permit lapsed[3]		30% [2]		
Tunstead	800	BL&C			Trial reported				
Westbury	728	LCUK	SLF trial suspended 2005		(24%)[1] 24,000[5]	Possible use			
Total permitted te	11,128,000		254,000		220,500	80,000		125,000	

Cement works	Annual cement production	Operator	SLF		Tyres chips or whole	RDF		Biofuels	
	Kilotonnes		RFO	Other		Profuel®	Climafuel®	MBM	PSP
Total permitted te of SF subject to successful trials			69,000		48,500	108,000		145,000	
Total te of SF in applications			50			35,000			

Notes:
1 Bracketed percentage figures are the equivalent maximum thermal substitution rate.
2 Limited details available.
3 Current status of SF trials.
4 Annual maximum permitted tonnes of SF subject to successful trials.
5 Annual maximum permitted tonnes of SF.
6 Annual maximum tonnes of SF in applications.
7 Application approved and trial reported.
8 Trials carried out in 2001, permanent use restricted by supply considerations.
9 Trials carried out in 2005.
10 Estimated figure.
11 Maximum figure.
12 Report on the trials is due February 2006.

Note that older plants, which do not burn SFs, have not been included. These are LCUK sites at Northfleet and Barnstone.

BCA forecast the growth in SF use by the year 2007 to reach:

- 1,260,000 tonnes SF excluding waste oils;
- 1,515,000 tonnes SF including waste oils.

The main increases in SF use from 2001 were suggested to be an SLF increase of 90,000 tonnes; tyres increase of 250,000 tonnes; packaging waste increase of 500,000 tonnes; MBM increase of 140,000 tonnes and PSP increase of 40,000 tonnes. Whilst this forecast is now outdated, it reflects the significant increase in SF tonnage sought in recent PPC variation applications. BCA also predicted the increased use of RDF-type fuels such as packaging waste, as well as biofuels such as MBM and PSP. However, the use of PSP is still currently limited to Cauldon works, where PSP burning in the calciner as well as in the kiln is now permitted.

The sector plan for the cement industry also envisaged an increase in the use of SF. The target for the proportion of fuel comprising waste material as a mass percentage was set to rise from 5.7 in the reference year of 1998 to 10 in 2006 and then to 15 in 2010. With SF trial applications now including greater use of MBM, RDF and SLF, it is clear that the BCA forecast of the use of 1.5 million tonnes per year of SF is a possibility, provided that cement producers can progress trials and secure the necessary SF supplies.

2.3.8 Potential substitute fuel use in UK cement industry

Whilst the UK cement industry has expanded the number of SFs used, there is scope to increase further the quantity and types of SFs. As previously stated, the cement-making process and cement quality parameters are sensitive to components such as chloride, sulphur, alkalis and P2O5. Therefore, the content of these parameters in the SF is an important factor which may limit the percentage thermal substitution that is possible with the SF or, in extreme cases, make the material unsuitable for use as a SF.

Implementation of the WID has brought RFO onto the market, as traditional outlets for RFO (coal-fired power stations and roadstone plants) cannot meet emissions requirements of the WID. Around 400,000 tonnes per year of RFO are generated in the UK. Greater use of waste oil-derived fuels can be seen with LCUK's plans to use RFO at the Aberthaw, Cauldon and Hope works. As the market is currently still in a state of upheaval, it is not possible to predict the long-term scenario for RFO. However, RFO can be blended into SLF and burnt without the need to vary the PPC permit, providing the mixture meets the current permitted SLF specification. The use of waste water and oily wastes does not appear to have attracted much interest from the cement industry.

Tyres have the advantage that the steel they contain can partially replace raw mix additives such as iron oxide and so reduce purchased raw material costs. The quantity of iron depends on the source of the tyres. There have, however, been supply issues with tyres; for example, Cookstown works carried out trials with tyres in 2001, but their permanent use was restricted by supply problems.

RDF may be produced under long-term contracts with municipal authorities and thus could be attractive in terms of security of supply and price. From municipal sources alone, the UK has the potential to produce at least 8.4 million tonnes per year of RDF, equivalent to 5.5 million tonnes of coal based on an assumed recycling rate of 40 per cent. SRF produced by the MBT process has the benefit of a 2:1 ratio of MSW used per unit of SRF produced. A few MBT plants, such as the one at Frog Island, are now operating in the UK. RDF is considered to have around 60 per cent biofuel content, but it has the disadvantage of a relatively low CV and higher chloride content than fossil fuel.

Greater use of PSP resulted from the successful trial at the Cauldon works with PSP burning in the pre-calciner. However, other plants have not taken up PSP, despite modern dry process kilns being suitable to burn PSP in their calciner units. Greater use of MBM is foreseen following successful trials at Ribblesdale, the trial evaluation phase at Aberthaw and trials planned for Hope cement works. A new bypass system is being installed in Kiln 8 at the Ketton works, which will allow greater use of fuels with high P2O5 and chloride content.

Biofuels, as well as partial biofuels (such as RDF), will become increasingly important to meet compliance with the EU ETS. Biofuels can help reduce overall CO2 emissions for the purpose of emissions trading, as the CO2 from biofuels or the biomass content of partial biofuels is treated as zero CO2.

2.3.9 Comparison with substitute fuel use in Europe

Use of SFs in the UK cement industry was relatively low between 1990 and 2003. Cembureau (European Cement Association) data indicate that only around six per cent SF by thermal substitution was burned during 2003[3]. This SF usage was slightly less than half the European average at the same time (12 per cent thermal substitution). SF thermal substitution varies considerably across European countries, with some countries such as Spain, Portugal and Ireland using very little and others such as the Netherlands, Switzerland and Germany having a very high usage. Growth in SF use in the UK cement industry has not matched that in key European SF user countries such as the Netherlands, Switzerland, Austria, Germany, Norway, France and Belgium where the substitution rates are 83, 50, 48, 38, 35, 34 and 30 per cent respectively. The new EU Accession States have relatively high substitution rates, which will increase the overall substitution rate in Europe. The latest BCA data show that SF use in the UK had grown to around 14 per cent in 2005 and is expected to grow further as more trials proceed. Cembureau data for 2003 to 2004 indicate an average SF use of 17 per cent amongst members.

Recent applications to burn new SFs send a clear message that UK cement producers wish to use significantly greater quantities of SFs, as well as a wider range of such fuels, in the future. At this stage, it is not clear whether the major UK cement producers have the necessary means to secure the tonnages of SFs permitted to be burned. However, Castle Cement (via SRM) and LCUK (via Sapphire) have taken positive steps to secure future SF supplies. Another factor which may encourage more rapid growth in SF use is the modernisation of UK cement works. For example, Castle Cement replaced five kilns (two wet process kilns at Ribblesdale plus two wet and one long dry process kiln at Padeswood) with the new Kiln 4 at Padeswood works. The recent application for Padeswood Kiln 4 allows for 100 per cent SF use, but the practicalities of plant commissioning are such that plant suppliers are unlikely to start up a new kiln on SFs alone. The approach adopted is to first establish performance on fossil fuels and then introduce SFs stepwise in a logical planned commissioning programme. SF use is expected to increase with other recent kiln installations (Rugby, Tunstead).

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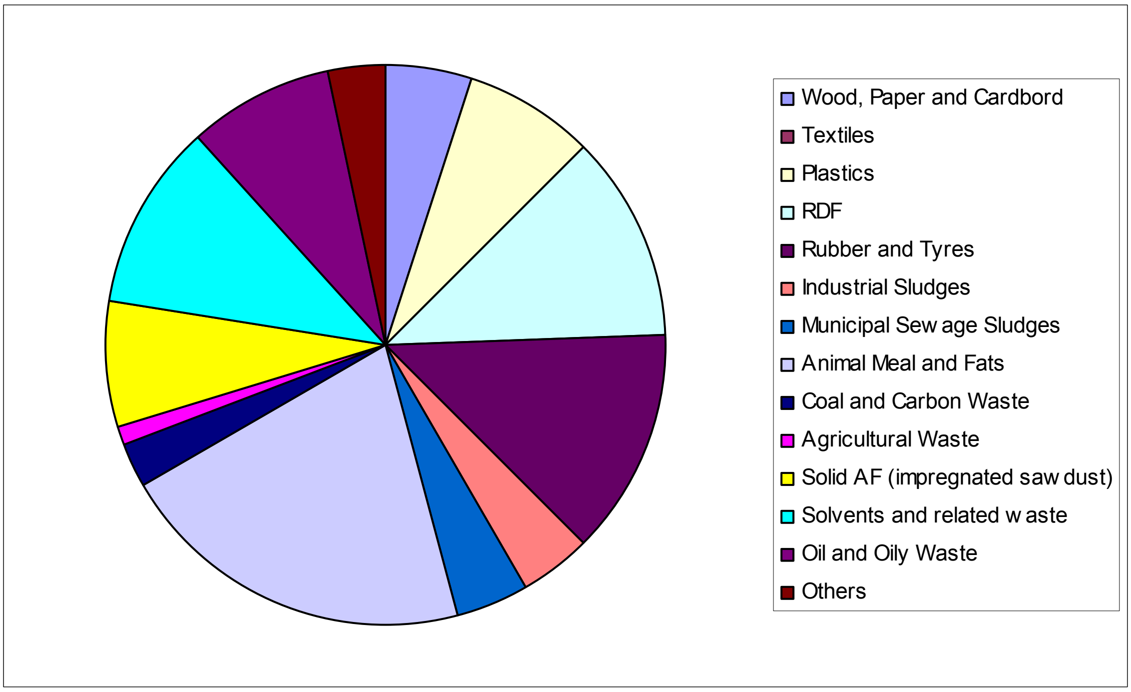
[3] BCA data indicate an 11.5 per cent use of SFs during 2004.

Modern pre-calciner kilns can be designed to burn the maximum quantities of SFs, because they have optimum combustion and efficient pollution control equipment. It is practical to install kiln bypass systems with modern pre-calciner kiln processes to allow a wide range of SFs to be burnt with the minimum associated heat and dust losses. Pre-calciner combustion chambers typically allow a five- to seven-second gas residence time, with 'hot spot' combustion chambers permitting the burning of difficult fuels.

In 2005, SF use in the UK was 268,351 tonnes per year compared with the potential permitted cumulative 'theoretical' tonnage of 1.085 million tonnes per year. The latter figure implies a potential thermal substitution rate in the UK of roughly 34 per cent (based on tonnage considerations[4]). This rate compares well with other European countries which are major users of SFs. A report produced by Entec[5] in 2005 noted that growth in SF use in Europe was expected to be 20 per cent by 2015 and 25 per cent by 2030. These figures may be conservative, as the EU has grown and international cement companies are extending into Eastern Europe and expanding the use of SFs using proven techniques and programmes.

The most recently published Cembureau data for 2004[6] indicate an increase in the average SF thermal substitution rate to 17 per cent. Total SF use during 2004 was 6.173 million tonnes, comprising 1.04 million tonnes of hazardous waste SF and 5.13 million tonnes of non-hazardous waste SF. Figure 2.3 shows the breakdown between types of SF.

Figure 2.3: Breakdown between types of SF used in 2004



[4] The actual thermal substitution rate will be lower, depending on fuel types and their calorific values. Note that the maximum SF tonnage cannot be used, as this would exceed the 100% substitution rate.

[5] Entec UK Limited. *Update on solid waste-derived fuels for use in cement kilns – An international perspective*. Environment Agency, 2005.

[6] Cembureau. *Cement and Lime BREF Revision, Cembureau Contribution 2003 and 2004 statistics on the use of alternative fuels and materials in the clinker production in the European cement industry*. 2006.

Between 2003 and 2004, there was a greater growth in non-hazardous waste SFs of 14 per cent, compared with 6.7 per cent growth in hazardous waste SFs. Changes in SF use between 2003 and 2004 showed the following trends:

- 41% increase in tonnage of wood, paper and cardboard;
- 55% reduction in tonnage of textiles (the total tonnage used is relatively small compared with other types of SFs);
- 31% increase in tonnage of plastics;
- 28% increase in tonnage of RDF;
- 51% increase in tonnage of sewage sludge.

Of the above trends, the growth in RDF fuels is similar to the trend in the UK. The growth in MBT plants in the UK will make more SRF fuels available from the processing of MSW. SFs such as Profuel® and Climafuel® include fuel sourced from MBT plants and the use of these SFs is expected to grow. MBM has been used in Europe for several years, but Cembureau data show a slight reduction in its use. There is no assessment of trends in the Cembureau data, but the lack of growth in MBM may be supply related. In the UK, use of MBM is expected to increase as it becomes a permitted fuel following trials. The major driving forces for the use of SFs, providing they achieve environmental acceptance via trials, are commercial and availability considerations. Since commercial data were not available for this study, it was not possible to establish which SFs have commercial advantages over others. In addition, the economics of using SFs are site-specific owing to transportation costs and source of supply.

In conclusion, it seems reasonable to expect future growth in MBM use and greater application of RDF in the UK in parallel to Cembureau reported trends.

2.3.10 Use of substitute fuels in UK lime industry

The use of SFs in the UK lime industry is limited to SLF (also know as solvent-derived fuel (SDF)) which is used at the two Steetley Dolomite Ltd lime plants at Whitwell and Thrislington.

Whitwell works

SLF/SDF is used at the Whitwell works up to 40 per cent thermal substitution. The permitted annual tonnage is a maximum 40,000 tonnes SLF or 80 kg per minute for each kiln (W1 and W2). The reported annual tonnage was 17,300 tonnes in 2004.

Thrislington works

SLF/SDF is used at the Thrislington works up to 40 per cent thermal substitution. Permitted annual tonnage is a maximum 50,000 tonnes SLF or 140 kg per minute in Kiln T3. Reported annual tonnage was 18,400 tonnes in 2004. Thrislington works has recently applied to burn up to 100 per cent SLF.

Table 2.6: Summary of data for 2004 lime plant use of SFs

Plant	Whitwell	Thrislington
Tonnage of SLF used	17,300	18,400
Thermal substitution %	17%	32%
Total consumption fuel (million GJ)	2.4367	1.3352
SLF supplier	SRM: Morecambe	SRM: Sunderland
Relevant environmental legislation	PPC, HWID, WID	PPC, HWID, WID

The environmental impacts of using SLF were reported as reductions in SO2 and NOX in the range of 20 to 40 per cent at both locations,

2.3.11 Potential fuels

By its nature the production of lime requires low ash fuels, and petroleum coke is the main fossil fuel used. SLF use is limited to the 40 per cent substitution maximum as specified for co-incineration within the WID. However, there are derogations from emission limit values (ELVs) for hazardous waste incineration specified in the WID for hazardous wastes, such as RFO and some other liquid fuels which meet certain specifications. In addition, non-hazardous waste oil-derived fuels may be an alternative option. Whilst trials with biofuels at lime kilns in the Far East have been known to take place, there does not seem to be any proposed use of these fuels in the UK. However, the current high price of gas and the EU ETS may lead lime operators to consider using SFs.

2.4 Regulatory Requirements and non-regulatory agreements Relating to the Use of Substitute Fuels

2.4.1 Waste Incineration Directive

Pollution Prevention and Control Regulations (England and Wales) incorporate the requirements of the WID[7] which apply to all cement works that co-incinerate waste materials covered by the directive. All SFs burnt in UK cement kilns to date are wastes and are covered by this directive. The aim of the WID is to prevent, or limit as far as practicable, negative effects on the environment from the incineration and co-incineration of waste. WID applies to most activities involving the burning of waste, whether for disposal or when used as fuel.

Annex II of the WID provides a formula (mixing rule) for the calculation of air ELVs for various substances, to be applied whenever a specific total ELV is not set out for the substance in Annex II. The calculation is made with exhaust gas volumes and ELVs laid down in both Annex II (co-incineration plants) and Annex V (incineration plants). ELVs for cement plants co-incinerating waste are not subject to the mixing rule and these are specified within Annex II.1 of the WID. If in a co-incineration plant more than 40 per cent of the resulting heat release comes from hazardous waste, the ELVs set out in Annex V (incinerators) apply. However, although incinerator limits will apply in this situation, the plant will not be classified as an incinerator.

Table 2.7 provides a comparison between ELVs for cement kilns operating as co-incinerators and for incinerators as specified in the WID.

[7] Directive 2000/76/EC of the European Parliament and of the Council of December 2000 on the Incineration of Waste.

Table 2.7: Emission limits for co-incineration in cement kilns and incineration

Directive requirement emission limit	Co-incineration in cement kiln ELV[1] mg/m^3	Incineration ELV2 mg/m3
Particulates	30	10
VOCs (as TOC)	10[3]	10
HCl	10	10
HF	1	1
NOx for existing plants	800	400[4]
NOx for new plants	500	200[5]
CO	[6]	50[7]
SO2	503	50
Group 2 heavy metals (cadmium + thallium)	Total 0.05	Total 0.05
Group 1 heavy metal (mercury)	0.05	0.05
Group 3 heavy metals (antimony, arsenic, lead, chromium, cobalt, copper, manganese, nickel, vanadium)	Total 0.5	Total 0.5
Dioxins and furans	0.1 ng/m^3 TEQ	0.1 ng/m^3 TEQ

Notes:

1 10% oxygen, dry gas.
2 11% oxygen, dry gas.
3 Exemptions may be authorised by the regulator in cases where TOC and SO2 do not result from the incineration of waste.
4 The NOX ELV of 400 mg/m3 applies to existing incinerators burning six tonnes per hour or less waste.
5 The NOX ELV of 200 mg/m3 also applies to existing incinerators burning more than six tonnes per hour waste.
6 Set by the regulator.
7 The CO limit does not apply on start up or shut down.

The limits for particulates, carbon monoxide (CO), NOx and SO2 are higher for cement plants co-incinerating hazardous waste than for incineration plants. This is because the primary source of these emissions is not the waste that is being co-incinerated, but the cement production process which is a high temperature process involving production of a dusty product. The requirements of the WID came fully into force on 28 December 2005. Variations to the PPC permits (WID variations) were issued by that date which brought in the new requirements. Further guidance on the WID is available from Defra[8].

[8] Defra. *Guidance on Directive 2000/76/EC on the incineration of waste*. Edition 3, 2006. This document is available from the Defra website.

2.4.2 Waste-related regulatory requirements

Implementation of the 1991 Framework Directive on Waste has introduced the following definition of waste:

“waste means any substances or object in the categories set out in Schedule 2B to the Environmental Protection Act 1990 which the holder discards, intends to discard or is required to discard.”

In light of European case law, the Environment Agency considers the use of any waste as a SF in cement kilns as a recovery operation for the purposes of the Waste Management Licensing (WML) Regulations 1994. The means that, in determining an application under PPC to use a waste SF the Environment Agency must, in addition to meeting the requirements of PPC Regulations, also meet ‘relevant objectives’ set out in Schedule 4 of WML Regulations. The Environment Agency must aim to ensure that burning SF poses no risk to human health, water, air, soil, plants or animals. In addition, the use of SF should not cause nuisance from odours or noise, nor should it adversely affect the countryside or places of interest.

The Hazardous Waste Directive, implemented by the Hazardous Waste Regulations, redefines hazardous waste and aims for greater harmonisation in the management of such waste. The directive prohibits the mixing of hazardous waste with other waste, except where it is a necessary part of the disposal operation, and places stricter controls on the carriers of hazardous waste. Hazardous waste producers are subject to periodic inspection; in addition, they and waste carriers must keep records of waste transactions for one and three years respectively.

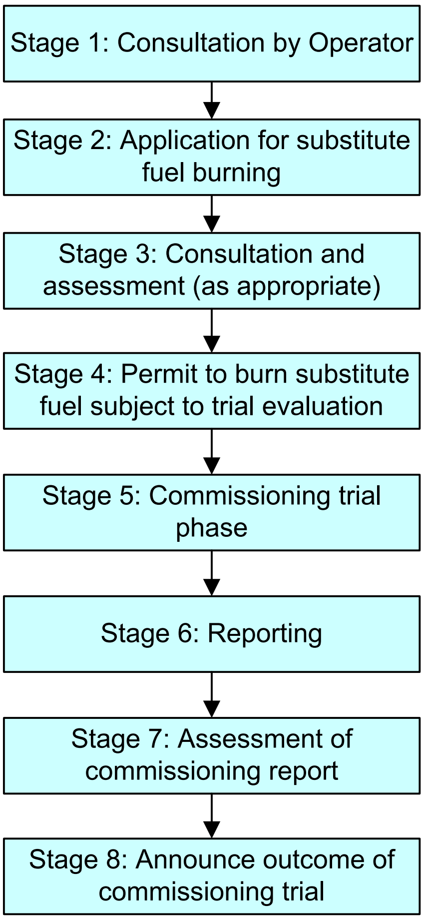
Waste transfers must comply with the Transfrontier Shipment of Waste Regulation, which requires Member States to ensure appropriate arrangements for movements of waste. In line with the EU’s aim for Member States to become self-sufficient in waste disposal, all waste should be treated or disposed of in an appropriate facility nearest to where it was produced. The regulation includes detailed procedures for pre-notification, authorisation and documentation of the waste and prior consent for transfrontier shipments.

In the regulation, waste for recovery or recycling is divided into three categories of red, amber and green according to how hazardous it is. Red waste includes PCBs, dioxins and asbestos; amber waste includes waste oils and petrol sludges; and green waste includes paper, glass and wood waste, waste from mining operations, textiles and rubber. For red and amber wastes intended for recovery or recycling, controls are the same as for shipments of waste for disposal. However, red wastes must have the written consent of authorities in the receiving country prior to shipment, while amber wastes may be shipped within 30 days of the receiving authorities acknowledging notification and no objections being raised. Green wastes should be accompanied by information about the shipment, including a description and the quantities involved.

2.4.3 Substitute Fuel Protocol

The burning of SFs in cement and lime kilns is also subject to the Substitute Fuel Protocol[9] (SFP). The Environment Agency protocol provides a consistent and transparent approach for cement and lime sectors to burn SFs. The PPC regime requires an operator to apply for a variation to the PPC permit in the event of a change in operation, such as a change in fuel use. The SFP sets out a procedure for doing this. Figure 2.4 shows the eight-stage procedure for permitting a new category of SF at an existing kiln.

Figure 2.4: Procedure for permitting a new category of SF at an existing kiln



During the third stage of the procedure, the operator proposes critical success factors (CSFs) which will be the benchmark from which to judge the use of SFs. These will normally include:

- no breaches of existing ELVs, caused by using the SF in question, that show that longer term compliance with the limits will be a problem;
- the amount of waste produced as a result of burning the SF will not increase significantly and will be within normal variations (the waste in this case includes recycled materials and reworked clinker);

[9] Environment Agency. *Substitute fuel protocol for use on cement and lime kilns.* 2000. This document is available from the Environment Agency website.

- there will be no net environmental detriment (barring any material change in the economics of the sector) to the local environment from SF burning. This assessment will be based on the Environment Agency's H1 method and will take into account other benchmark criteria to protect the environment;

- inspections of SF burning operations will receive acceptable assessments in line with current Environment Agency compliance assessment methods;

- there will be no significant increase in abnormal operations from SF burning.

Further information on the SFP can be found in Annex B.

2.5 Review of compliance for cement works using substitute fuels

The Environment Agency operates the Compliance Classification Scheme (CCS) as the means of recording non-compliances under the Integrated Pollution Control (IPC) and PPC regulatory regimes. The scheme has been operating since 1995. Non-compliance is assessed and classified under the scheme in terms of its potential impact on the environment. Once this information has been recorded in the CCS database, any findings or actions taken are put into the appropriate site file.

The Common Incident Classification Scheme (CICS) is used to classify the non-compliance score. Where actual impact on the environment has occurred as a result of non-compliance, the potential impact under the CCS classification will be equal to or greater than the actual CICS classification for an incident. Where there is no actual impact on the environment resulting from non-compliance, the potential impact is considered. If, in the Inspector's judgement, the potential impact could have been higher (in the case of a near miss scenario) and could reasonably be expected to have occurred, the Inspector needs to decide on the seriousness of the impact that could have occurred and assign the appropriate CCS classification. Table 2.8 provides the compliance classification scheme matrix for the IPC and PPC regulatory regimes.

Table 2.8: Compliance classification scheme matrix

Category	Description	Example
1	A non-compliance that caused or had the potential to cause major extensive harm	Any non-compliance with the potential to cause a CICS Category 1 incident, for example where poor maintenance of plant or pipework would result in an increased risk of releasing significant amounts of toxic material to the environment
2	A non-compliance that caused or had the potential to cause significant localised environmental harm	Any non-compliance with the potential to cause a CICS Category 2 incident, for example where the risk or amount of material released is lower than above, but the local environmental impact could still be significant
3	A non-compliance that caused or had the potential to cause minor localised environmental harm	Any non-compliance with the potential to cause a CICS Category 3 incident, such as exceedance of a permit release limit which could lead to a localised minor environmental impact like sight, smell or noise but which is contained locally and quickly corrected by operator response without any lasting impact
4	A non-compliance that had no potential to cause environmental harm	Non-compliance with no potential to cause environmental harm will normally be limited to a CICS Category 4 incident

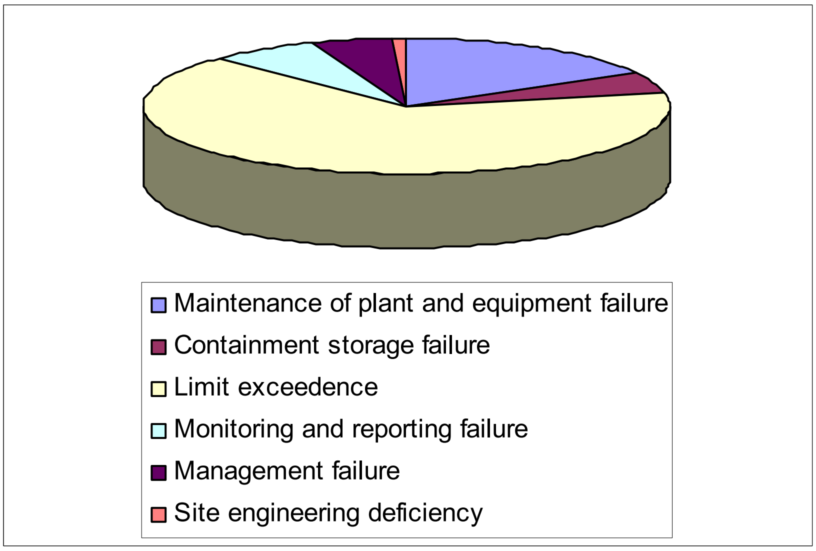
Hence in most cases, the CCS classification for non-compliance is the same as the actual environmental impact classification defined under CICS for incident severity assessment. However, some circumstances of non-compliance could potentially have had a greater environmental impact and this should be classified as a higher CCS category. An example of this is where third party intervention or fortuitous circumstances have mitigated the effect of an incident arising from a breach of a permit condition.

Under CICS, an impact category must be assigned for each of the environmental media: air, land and water affected. The method also applies to complaints of noise associated with the site, including installations permitted under Part A(1) of the PPC regime.

The CCS database was designed to deliver high level information, so it is not possible to gain much insight from the data. There were no Category 1 incidents and only one Category 2 incident at cement works during 2005. The latter was a management failure at Aberthaw not directly related to SFs.

Figure 2.5 provides a sectoral overview of the types of Category 1 to 4 incidents that occurred in 2005. The majority of incidents related to emission limit exceedances, with maintenance of plant and equipment failure being the next most frequent type of incident.

Figure 2.5: Sectoral overview of types of Category 1 to 4 incidents in 2005



The Environment Agency's National Enforcement Database, which holds information on enforcement actions, provided the information shown in Table 2.9 on cement plants.

Table 2.9: Information on cement plants from the National Enforcement Database

Year	Enforcement actions
1999	Two enforcement notices
2000	Two enforcement notices and four prosecutions
2001	Two enforcement notices and three cautions
2002	None
2003	One enforcement notice
2004	Two enforcement notices
2005	One enforcement notice and three cautions

Table 2.9 shows that the only year in which there were prosecutions was the year 2000 and there were no enforcement actions in 2002.

2.6 Nature and extent of consultation comments in response to applications to use substitute fuels

The Environment Agency received more consultation comments in response to applications to use SFs from non-statutory consultees than from statutory ones. Most statutory consultees broadly agreed with the applications on the basis that emissions would not exceed current thresholds. Consultees requested to be informed about any amendments to the draft permits and to receive copies of the permit conditions. Some statutory consultees specified a number of conditions (for example, on the scope of monitoring) that they wanted to see included in the permits. The majority of public comments required further information to satisfy their doubts and insisted that the Environment Agency set stricter requirements. However, some public feedback was supportive, recognising the positive environmental effects associated with the use of SFs.

The majority of the received comments could be divided into the following groups: environmental impacts; public health concerns; possible odour nuisance; effects on food chain; safety issues; and general issues.

2.6.1 Environmental impacts

Most comments on environmental impacts concerned air quality and its effects on public health. Some consultees questioned the quality of monitoring equipment and demanded an increase in the range of pollutants measured and the frequency of measurement. The Environment Agency responded that it considered the equipment to be acceptable and was satisfied with the scope and frequency of monitoring. In particular, the Environment Agency believed that the focus of ambient monitoring should be on NOx and SO2, the only environmentally significant emissions from installations, although it specified that CO, PM10 and PM2.5 would also be monitored. The operator and the Environment Agency would carry out monitoring to obtain independent data. With regard to benzene, 1,3-butadiene, heavy metals, dioxins and furans, the Environment Agency stated that there was no justification for ambient monitoring of these species, but monitoring of stack emissions would assess emissions of these substances, along with halogens.

Another air quality comment related to the 'de-novo synthesis'. The Environment Agency responded that it was confident that exhaust gases were at temperatures well below those required for 'de-novo synthesis' before they passed through the ESPs and entered the stacks where they were monitored. Concerns were also expressed over emissions generated during start up and shutdown periods. In this case, the Environment Agency reassured the consultees that these emissions were not related to the use of SFs, as the permit variations prohibit their combustion during these periods.

Environmental concerns included the need to minimise vehicle movements associated with new operations, to prevent an increase in emissions.

2.6.2 Public health concerns

Local residents were concerned with the state of public health in the area (chesty and tickling coughs, asthma and so on) and/or possible detrimental effects of burning SFs. The Environment Agency, supported by statutory health consultees, responded with the belief that the new operations would not have an unacceptable impact on human health. The impacts of emissions were judged against the UK Air Quality Strategy (AQS) and international (World Health Organisation (WHO)) air quality guidelines and standards. The response included the statement that the incidence of increasing asthma is not localised and appears to be a nationwide trend.

2.6.3 Odour nuisance

Local residents were worried about potential odour nuisance. The Environment Agency recognised this importance of this issue and stated that it would need to be reassured that ventilation air from storage facilities would be combusted or vented through filters to remove VOCs and any residual odour. The Environment Agency also stated in one case that the RLF storage facility would be nitrogen blanketed. In addition, it was emphasised that no odour would be released from the kiln stack, as SF combustion completes within the kiln.

2.6.4 Effects on food chain

Another group of comments related to effects on the food chain. Consultees requested that the Food Standards Agency (FSA) monitor the effects on milk and other foods before, during and after trials. In the case of the Westbury works application, the FSA accepted that the operator's monitoring programme should cover additional data to assess risks to the human food chain. The Environment Agency also included a condition for soil monitoring at the end of the trial. For the Ketton works application (2 August 2000), the FSA had carried out an assessment to determine food safety implications of the Profuel© trial. The study concluded that this process would not lead to an unacceptable increase in levels of metals and dioxin in the food chain, but there were reservations regarding a possible increase in polycyclic aromatic hydrocarbons (PAHs). The Environment Agency did not believe that the new process would increase PAH emissions, since PAHs would be destroyed under cement kiln combustion conditions. However, improvement conditions were included in the permit variation to confirm this understanding and the works already monitored PAHs.

2.6.5 Safety issues

A number of comments were recorded on safety issues, including safety of delivery, storage and use of SFs. The Health and Safety Executive (HSE) responded that they would continue to assess handling and storage of SFs on routine inspections of the cement works. Also, it was emphasised that the inspection technique and inspectors employed were the same as for chemical works, although risks and impacts associated with the latter were significantly higher. The responses noted that there were a number of interlocks built into control systems on the kilns to control the operation process, in particular the SF feed supply. In addition, the operators' emergency plans had been reviewed and revised.

Some consultees were concerned that the cement produced would be contaminated with dioxins and heavy metals. The Environment Agency's response emphasised that dioxin concentrations in cement do not pose a significant risk to employees or members of the public. The Environment Agency noted that the use of RLF does not influence the presence of heavy metals in cement and the use of SF does not cause leaching of toxic substances from cement. In addition, it was stated that these substances are present in the naturally occurring raw starting materials (limestone and clay). Extensive leaching testing was carried out for the Ketton works application.

2.6.6 General issues

Comments of a more general nature included questions on the legal framework and justification for hazardous waste disposal at the cement works. The Environment Agency responded that cement making requires significant heat input and the intention is to provide part of this heat by burning SFs. Cement kilns have a number of characteristics (such as high temperatures maintained over long periods of time), which are advantageous for the destruction of the organic proportion of wastes used as SF. The Environment Agency noted that the material is classified as hazardous waste, but its use as a fuel in cement making is classified as a recovery operation in which the energy content of waste is used. This is in line with the Government's Waste Strategy, the waste hierarchy and sustainability principle.

Following comments on the need to undertake an environmental impact assessment (EIA), the Environment Agency responded that it did not consider that applications for variations involved 'development consent' for EIA purposes. However, the Environment Agency was satisfied that the variation applications substantially complied with the requirements of the directive, particularly in terms of public consultation.

2.7 Prevention of the use of substitute fuels for environmental, planning or other legislative reasons

No examples of the prevention of use of SFs for environmental, planning or other legislative reasons were identified in this review. However, three cases of SF trials being halted for other reasons were found, the first of which related to tyre burning at the Westbury works. Trial 3 on Kiln 2 with up to 40 per cent thermal substitution was started on 1 June 1998, but was halted by the Environment Agency on 11 June 1998 following a breach of one of the trial conditions. After a number of improvements had been made, the Environment Agency permitted the trial to continue from 22 March 1999.

A tyre chip burning trial at the Rugby works that started in May 2004 was halted on 1 July 2004, as a precautionary measure, following a breach of the permitted emission concentration for particulate matter. The breach was due to a fault in the ESP and the works had continued to burn chipped tyres in contravention of permit conditions. The Environment Agency served a notice requiring new operating procedures to be put in place before the trial was allowed to resume. The trial resumed in October 2005.

The third case involved an RLF burning trial at the Westbury works, which was suspended owing to reasons not directly related to the SF. LCUK alerted the Environment Agency to the fact that data on cement quality had been falsified between 2002 and 2004. The Environment Agency immediately started a comprehensive audit to check whether there were any implications for the environmental monitoring data for the works. At the same time, it refused to allow the fuel trial to start until the investigation was complete and confidence was fully restored. The audit showed that the environmental management system at the works was robust and that data received by the Environment Agency were sound. However, the failure to report one minor exceedance of a cement dust limit was discovered, which led to the Environment Agency issuing a formal warning to LCUK.

2.8 Delivery, Storage and Handling of Substitute Fuels

The WID specifies the following requirements for the delivery and reception of wastes, which have to be addressed prior to acceptance of the waste:

- determination of the mass of each category of waste, if possible according to the European Waste Catalogue;
- collation of all administrative information on the generating process for the waste in documents required by Directive 91/689/EEC on hazardous waste and, where applicable, documents required by Council Regulation (EEC) No 259/93 on the supervision and control of shipments of waste within, into and out of the EU and by dangerous goods transport regulations;
- collation of all information on the physical, and as far as practicable, chemical composition of the waste and all other information necessary to evaluate its suitability for the intended co-incineration process;
- collation of all information on the hazardous characteristics of the waste, the substances with which it can be mixed, and the precautions to be taken in handling the waste;
- checking of documents required by Directive 91/689/EEC on hazardous waste and, where applicable, documents required by Council Regulation (EEC) No 259/93 on the supervision and control of shipments of waste within, into and out of the EU and by dangerous goods transport regulations;
- taking of representative samples unless inappropriate (such as for infectious clinical waste) as far as possible before unloading, to verify conformity with the information listed above by carrying out controls and to enable the appropriate agency to identify the nature of wastes treated. These samples shall be kept for at least one month after incineration.

Annex E provides details of substitute fuel handling and usage in the cement kilns at various works in the UK. This includes usage of Cemfuel®, Profuel®, tyres, MBM and PSP.

2.8.1 Cemfuel®

Cemfuel® is a highly specified liquid fuel manufactured from liquid and solid hazardous waste organic materials by SRM. The specification of the fuel is tailored to meet the chemistry of cement manufacture. Solid wastes are ground, pulverised and suspended in a liquid carrier and blended to the Cemfuel® specification. There is a pre-screening stage for the waste prior to blending.

Table 2.10 provides the specification of Cemfuel® for the Ketton works. The composition of Cemfuel® has been modified in the past when the Ketton works has used higher quantities of Cemfuel®. The main differences with high substitution rates were lower concentrations of cadmium, titanium, cobalt, copper, lead, nickel, tin and vanadium.

Table 2.10: Cemfuel® specification for Ketton works

Constituent	Concentration (ppm unless otherwise stated)
Calorific value gross	21 - 42 MJ/kg
Sulphur	0.5 - 1.0% w/w
Chlorine	1.6% w/w = 16,000 g/tonne
Fluorine	0.5% w/w
Mercury	20
Total group II metals (cadmium + thallium)	50
Total group III metals	1,800
PCBs	10 g/tonne
Pentachlorophenol	100 g/tonne

Table 2.11 provides the specification of Cemfuel® for use in Kiln 7 at the Ribblesdale works.

Table 2.11: Cemfuel® specification for Ribblesdale works

Constituent	Concentration (mg/kg as maximum unless otherwise stated)
Calorific value	23 - 42 MJ/kg
Sulphur	1.0% w/w
Chlorine	2.0% w/w
Fluorine	0.3% w/w
Bromine	0.3% w/w
Iodine	120 mg/kg
Total fluorine, bromine and iodine	0.5% w/w
Mercury	20
Cadmium and thallium in total	40
Antimony	200
Arsenic	50
Chromium	500
Cobalt	100
Copper	600
Lead	500
Manganese	100
Nickel	100
Tin	50
Vanadium	50
Total group III metals	1,800
Solids	20%
Ash	5%
Water	20%

2.8.2 Tyres

SER manages the used tyre supply chain. This includes collection of 'end of life' tyres from 20,000 collection points in the UK. Collection is on a daily basis. Tyres are transported to a processing centre, of which there are nine in the UK, and processed to enable use in the cement industry. Tyres used at the cement plants can be car, van or truck tyres, but the use of one particular type of tyre is maintained at each cement works. For the dry cement process, tyres are cut into five to 12 cm chips by machinery before use. Prior to chipping, the tyres are cleaned. Tyre chips are introduced into the bottom of the pre-heater tower of the cement kiln. In the wet cement process, whole tyres are inserted into the middle of the kiln.

Table 2.12 shows the typical constituents of the rubber content of tyres.

Table 2.1: Typical constituents of the rubber content of tyres

Constituent	Percentage
Rubber	51
Carbon black (filler)	26
Oils (paraffin and aromatic)	13
Zinc oxide	2
Sulphur (vulcanised)	1.0 - 1.5
Halogens	0.5
Others	6

Tyres contain steel, which can partially replace raw mix additives such as iron oxide and thereby help to reduce raw material costs for the cement process. The quantity of steel depends on the source of tyres, as shown in Table 2.13.

Table 2.13: Typical major components of tyres

Vehicle	Tyre type	% rubber compound	% steel	% textile
Car	Steel braced radial	86	10	4
Car	Textile braced radial	90	3	7
Car	Cross-ply	76	3	21
Truck	All steel radial	85	15	< 0.5
Truck	Cross-ply	88	3	9

The components of used tyres will vary considerably depending on the degree of wear, the type of tyre (car or truck) and the type of bracing used. Materials used in reinforcement include steel, rayon, fibreglass and polyester. The rubber may be a mixture of natural and synthetic rubber.

At the Cookstown works, the handling and firing system for whole tyres consists of the following processes:

- weighing followed by storage of the tyres in designated areas in controlled stacks that are sized and spaced to comply with fire safety requirements;
- transportation of the tyres to the kiln, which is limited to no more than 50 tyres at any one time;
- introduction into the tyre box via a hinged lid which is then closed so that the tyres are pushed via a ram into the zone above the calciner region of the Lepol grate. The tyres are held on heat-resistant SIFCA® (Slurry Infiltrated Fibre Castable, a trademark of Wahl Refractories) 'fingers' above the grate where the gas temperature is around 900ºC. After retraction of the ram, the cycle is repeated for the next whole tyre. The system is designed to use up to 90 tyres per hour, equivalent to a 12 per cent thermal substitution rate.

Tyre chips are generally the preferred option compared to whole tyres for modern cement plants. Higher addition rates can be achieved with tyre chips which are more easily combusted compared to whole tyres. Also, the addition of tyre chips rather than whole tyres provides better and smoother operational control. The Dunbar works handling and firing system for tyre chips consists of the following items:

- a large storage area for whole tyres ready for chipping;
- a chipping machine for car tyres (preferable to truck tyres as their steel ply content is lower, where a high steel content reduces the life of the machine);
- a large storage area for chipped tyres;
- a loading machine to load the chipped tyres into reception hoppers (i.e. machine known as a Saxland Box Feeder);
- the feeder which distributes the tyre chips onto a conveyor belt which travels to the pre-heater tower;
- a rotary feeder which introduces the tyre chips into the pre-heater.

2.8.3 Profuel®

Profuel® is a highly specified solid fuel manufactured from dry organic wastes. It used to be made solely from packaging waste from all types of manufacturing processes, including thin offcuts of foils, paper and plastics from the manufacture of products such as nappies and crisp packets. These residual materials are either uneconomic or unsuitable for recycling. More recently, RDF and SRF have been used to produce Profuel®, and the current composition of Profuel® varies depending on the wastes used for its production.

In order to decide whether a packaging material is suitable for Profuel®, SRM takes a sample of waste from the producer. The producer is asked to complete a questionnaire detailing the general physical make-up of the waste. SRM then carries out a laboratory analysis to identify the key components of the packaging waste and its combustion characteristics. If found suitable for inclusion in Profuel®,, the packaging waste is collected by SRM using the links established with the cement industry. At the Profuel® factory, the wastes are inspected on arrival and categorised for subsequent blending. The materials are then shredded, ground to a size of around 20 mm and blended to meet the final kiln specification.

Table 2.14 provides a detailed analysis of proposed packaging materials to produce Profuel®.

Table 2.14: Analysis of proposed packaging materials to produce Profuel®

Determinant	Units	Sawdust	Nappies	Medical rubber	Photo paper	X-ray acetate	Carpet	Coffee grounds	Mean
Ash	%	4.1	0.84	22.5	4.11	2.47	2.55	1.05	5.37
Chlorine	%	0.15	0.17	0.11	0.33	0.15	0.13	0.1	0.16
CV (gross)	MJ/kg	14.37	32.71	26.45	23.26	22.93	17.65	23.39	22.97
Sulphur	%		0.02			0.19			0.11
Mercury	ppm					0			0
Cadmium	ppm	10	10	10	10	10	10	10	10
Titanium	ppm	10	10	10	10	10	12	10	10.29
Copper	ppm	17	10	10	10	10	10	35	14.57
Cobalt	ppm	10	10	10	10	10	10	10	10
Zinc	ppm	100	49	824	42	98	21	28	166
Lead	ppm	151	10	11	11	10	21	10	32
Chromium	ppm	21	10	14	10	10	10	10	12.14
Nickel	ppm	10	10	26	12	10	21	10	14.14
Manganese	ppm	120	10	10	10	10	39	18	31
Tin	ppm	38	10	58	10	10	35	10	24.43
Antimony	ppm	39	20	43	36	46	22	30	33.71
Vanadium	ppm								

At the Ketton works, the Profuel® handling system consists of the following:

- a covered storage area in a building adjacent to Kiln 7;
- a granulator which is used to reduce fuel particles to a suitable size (expected to be two to10 mm);
- initial fuel transport to the storage system in which Profuel® is fed by rotary valve into a transport line and is pneumatically conveyed to a storage silo. The silo is vented to atmosphere via a de-dusting filter equipped with explosion relief vents;
- the fuel feed system in which Profuel® is extracted from the silo by means of metering screws and a rotary valve. The Profuel® is then blown through a transport line into the kiln firing pipe. The firing pipe is also used for firing of coal and petroleum coke pulverised fuel;
- in Kiln 7, a pre-heater process kiln which does not benefit from a large pre-calciner or enlarged riser duct for fuel combustion, Profuel® is fired in the kiln main burner;
- in Kiln 8, where Profuel® is fired in the calciner vessel of the kiln, Profuel® is extracted from the silo by feed screws and a rotary valve and is blown through a transport line into the calciner firing system.

2.8.4 Meat and bone meal

In May 1996, the Government introduced the Over Thirty-Month Scheme (OTMS) to provide an outlet for cattle that could no longer enter the food chain as a result of the OTM Rule. The OTM Rule was introduced to eliminate BSE. The OTMS operated under EC Regulation 716/96, which required carcasses processed under OTMS to be incinerated or sent to a rendering plant for processing and destruction. Most carcasses were rendered, with the MBM and tallow produced being safely stored pending destruction. BSE testing for OTM cattle was developed in 2005 and in November 2005, a system of testing OTM cattle was introduced. At this time, the OTM Rule was replaced by a robust BSE-testing regime to allow cattle born after 1 August 1996 back into the food chain, subject to testing negative to BSE. Cattle born before 1 August 1996 continue to be excluded from the food chain and the Older Cattle Disposal Scheme (OCDS) provides for the disposal of and compensation for cattle born before this date.

MBM that is burnt at cement works is obtained from waste from the preparation of meat for human consumption. This MBM has never been produced from the rendering of animal waste from the OTMS. In fact, PPC permits allowing the burning of MBM stipulate that MBM cannot be produced from the rendering of animal waste from the OTMS as long as the scheme remains in force.

Table 2.15 shows the limits applied to MBM at various works.

Table 2.15: Limits applied to MBM

Constituent	Ribblesdale Kiln 7	Ketton average sample analysis	Aberthaw
Maximum % thermal substitution	50%	K7 40% K8 with bypass 50%	30%
Calorific value MJ/kg	15 - 23	19.1	14 - 22
Sulphur % w/w	1	0.39	1.5 max
Chlorine % w/w	2.0	0.74	0.75 max
Phosphate % w/w	7	3.62	15 max

At the Aberthaw works, MBM fuel transportation and transfer systems have been designed to ensure maximum enclosure with minimum opportunity for fugitive emissions to the atmosphere, and consist of the following:

- bulk lorries transporting MBM to the works discharge the material to silos using a fully enclosed mechanical conveying system;
- the MBM silo is equipped with material temperature monitors and a silo inerting system. The silo is also fitted with explosion relief (of the self-closing type, fitted with a vacuum break);
- the silo content is measured and protected from overfill by a sonic-type level device. The offloading and silo-filling processes are interlocked so that in the event of a high level indication from the silo or a fault on the plant, the whole process is shut down;
- MBM is removed from the bottom of the silo using a hydraulically driven screw system and is fed to the kiln firing system;
- a secondary firing system is used to fire coal or petroleum coke pulverised fuel to the kiln riser duct as part of the auxiliary firing system;
- any air displaced from the kiln system during the discharge of MBM is either vented into the kiln firing system or vented through carbon absorbers before being released to atmosphere.

2.8.5 Processed sewage pellets

PSP is produced from the sludge remaining after sewage treatment by drying and heat treatment.

Table 2.16 shows the limits applied to PSP at the Cauldon works.

Table 2.26: Limits applied to PSP at the Cauldon works

Constituent	Limit
Maximum % thermal substitution	40%
Calorific value MJ/kg	14 - 21
Sulphur % w/w	1
Chlorine % w/w	0.3
Phosphate % w/w	2

At the Cauldon works, the PSP transportation and transfer system for phase 2 calciner firing includes milling and then injection into the main burner as follows:

- transportation of fuel during which the fuel is handled within a totally enclosed system which allows no opportunity for fugitive emissions to the atmosphere and removes the need for direct manual handling at any stage. PSP is transported to the Cauldon works in purpose-built sheeted walking floor trailers. The multi-axle trailers are capable of carrying up to 30 tonnes of PSP. The trailers are unloaded by the movement of sections of the trailer floor, which are powered by a hydraulic power pack, mounted independently of the tractor trailer unit. The walking floor trailer is then coupled to a fixed facility (incorporating the hydraulic unit) at the works. Once coupled, the transfer facility will automatically unload the PSP via a totally enclosed system to the designated PSP silo;

- the transport and storage for phase 2 pre-calciner firing is housed in the same building as phase 1 and comprises:

    - an inter-connecting screw conveyor;
    - a second 75-tonne storage capacity silo;
    - a second low exhaust volume silo dust plant;
    - a silo discharging device (active transfer);
    - a loss-in-weight pressurised feeding and lean phase blowing system;
    - a conveying line from the silo to the calciner fuel dosing point.

- the transfer and storage facility is located inside a converted building, with the storage silo protruding partially above the roof. Feed from the walking floor trailers is via a close-coupled reception hopper, which uses screw conveyors and a slow-moving elevator to reach silos 1 and 2. The facility is vented by local exhaust ventilation (LEV) dust plants sited on top of silos. The elevator is equipped with a suitably sized and sited self-closing explosion panel;

- PSP silos have a working capacity of 75 tonnes. The section protruding from the roof is insulated in order to prevent condensation and maintain a consistent temperature. Silos are equipped with material temperature monitors, CO2 dousing equipment and explosion relief. The silo content is measured and protected from overfill by sonic-type level devices. Offloading and silo-filling processes are interlocked so that in the event of a high level indication from the silo or a fault on the plant, the whole process is shut down;

- for silo extraction, the new system can use PSP in its pelletised form. PSP passes through a loss-in-weight dosing system and is fed to a lean phase conveying line for transport to the pre-calciner vessel.

2.8.6 General preconditions and safety interlocks

To ensure that the firing of SFs is carried out in a safe manner, with minimum impact on the environment as well as kiln stability, a number of preconditions and safety interlocks are specified within PPC permits. Details of these vary from plant to plant; however, the following are typical examples of preconditions applied to SF-burning kilns:

- process fan preconditions:

    - ESP or baghouse-induced draft (ID) fan running;
    - pre-heater/kiln main ID fan running;
    - primary air fan running for main kiln burner.
    - for CO preconditions, CO in electrostatic precipitator should typically be below 0.45 to 0.6 per cent, depending on the plant and its permit conditions.
    - operating temperature preconditions:
    - for the pre-calciner vessel, a typical minimum temperature of 850ºC may be specified for the calciner or lower cyclone stage outlet temperature;
    - for the pre-heater kiln, a typical minimum temperature of 810ºC may be specified for the lower cyclone stage outlet temperature

in the kiln back-end riser duct. The riser duct temperature for Ketton Kiln 7 is specified as greater than 500ºC.

- some typical minimum kiln feed rate preconditions are shown in Table 2.17.

Table 2.17: Minimum kiln feed rate conditions

Plant and kiln process	Minimum feed rate tonnes/hour	Clinker tonnes/day
Ketton Kiln 7 – pre-heater – SP4	45	1,450
Ketton Kiln 8 – pre-calciner – SP4	120	1,450
Ribblesdale Kiln 7 – pre-calciner – SP4	less than 80 tonnes/hour clinker = 1,920 tonnes/day	2,620
Cookstown – Lepol	65 (RLF)	
Barrington – wet	42	

The conditions applied to Hope works Kiln 1 shown in Table 2.18 provide an example of the process operating conditions applied to tyre chip burning.

Table 2.183: Process operating conditions for Hope works Kiln 1

Operating parameter	Minimum allowable value	Target value	Maximum allowable value
No 1 pre-heater exit CO concentration mg/m^3	Above zero	0.15 - 0.2%	0.4%
Bag filter exit NOx concentration mg/m3	Above zero	650	700
No 1 pre-heater exit O2 concentrations mg/m^3	1.5	4.0	4.0
Primary air flow kg/hour	21,000	23,000	27,000
Coal mill outlet temperature ºC	60	80	90
Coal mill separator speed	140	160	180
Kiln feed tonnes/hour	120	140	165
Derived burning zone set point ºC – camera pyrometer	1,250	1,300	1,350
No 4 pre-heater cyclone exit temperature ºC	850	855	860
No 4 pre-heater cyclone inlet temperature ºC	850	850+	860
Tyre chip feed rate	0	2 tonnes/hour	average in one hour: 2 tonnes
Bag filter inlet temp ºC	-	200	No limit
Bag filter Nos 1-8 compartment outlet dust indication	-	Below 40 mg/m^3	40 mg/m^3

Limits were imposed for the stage 4 cyclone gas temperatures (reported above as No 4 pre-heater inlet and exit temperatures), the maximum tonnage (two tonnes per hour tyre chips) and pre-heater exit gas O2 and CO levels. The PPC permit mentions steps that must be taken to ensure that the burning of tyre chips cannot take place unless kiln operating conditions are stable. This requires, for example, that “an interlock will be fitted to No 1 Kiln tyre chip feeding mechanism. This interlock will prevent the addition of tyre chips at any time that process conditions fail to meet the authorised levels (for example, if the temperature at the gas inlet to number 4 feed cyclone falls below 850ºC). In addition, the feeding of tyre chips will be stopped manually if the emissions from the process exceed the authorised limits.”

The PPC permit for Ribblesdale Kiln 7 provides an example of conditions applied when several SFs are being burned. The SFs are tyres (maximum of 25% in the riser duct), Cemfuel® (maximum of 40% in the kiln only) and MBM (maximum of 50% in the riser duct). The plant is equipped with a wet scrubber to reduce SO2 emissions. The permit variation includes the statement that "substitute fuels shall not be burned, or shall cease to be burned as soon as practicable on Kiln 7 during periods of unstable operation if:

- the kiln is in start up(as agreed in writing with the Environment Agency);
- the kiln is in shutdown (as agreed in writing with the Environment Agency);
- any continuous ELV in Table 6.1.3 is exceeded;
- clinker production is less than 80 tonnes/hour;
- monitoring results required to demonstrate compliance with any continuous ELV in Table 6.1.3 are unavailable for a period of four hours uninterrupted duration;
- any other continuous monitors for temperature, pressure, oxygen and moisture on Kiln 7 chimney are unavailable for a period of four hours uninterrupted duration;
- the cumulative duration of periods of continuous emission monitors (CEMs) failure over one calendar year on the kiln exceeds 60 hours;
- when the concentration of carbon monoxide at the precipitator inlet is greater than 0.6% v/v;
- when the scrubber is not running."

LCUK provided examples of the procedures adopted at Cookstown works to ensure safe handling of SFs as well as quality control. Documentation included:

- special waste regulations and transportation documentation in the form of a Powerpoint presentation explaining Section 62 documentation used to ensure a fully auditable system is in place when delivering SLF to Cookstown works. The Environment and Heritage Service is the regulator for the Cookstown works and for this reason, slightly different documentation procedures reflect the situation in which SLF is blended at SRM and shipped from Heysham to Belfast Docks. The process requires the use of two Section 62 notes instead of a single note as used in England, Wales and Scotland;

- written procedures for the use of SLF including the following 19 procedures:
    - RLF authorisation and delivery scheduling;
    - documentation;
    - tanker offloading;
    - tanker sampling;
    - bund sump operation;
    - tank agitation;
    - emission limits;
    - kiln RLF interlocks;
    - feeding RFL to the kiln;
    - shutting down the RLF to the kiln;
    - spills and leaks;
    - tank rupture;
    - fires;
    - daily inspections;
    - sampling VOCs at carbon filter vent;
    - sampling liquids in bund areas;
    - offloading pump stoppages;
    - returning RLF spillage to tank;
    - tank cleaning.

Castle Cement provided a duty of care pack for the use of Cemfuel® at the Ketton works. The documentation was extensive and included a Cemfuel® batch acceptance procedure which provided information on the following areas:

- responsibilities;
- acceptance of Cemfuel® prior to delivery;
- persons who can accept Cemfuel® batch analysis;
- blending and analysis of Cemfuel®;
- concessions;
- approval of Cemfuel® batches.

There was also supporting documentation which covered the following areas:

certificates;

- waste disposal policies;
- relevant insurance;
- HM Customs and Excise licences.

2.8.7 Conclusions

A considerable amount of thought has gone into developing safe procedures to cover all interrelated aspects of transportation, quality and use of SFs in cement kilns. For SF deliveries, this includes ensuring that the quality and quantities are auditable, with procedures to reject deliveries if strict parameters are not adhered to.

Suitable substitute fuel (SF) handling systems have to be developed for the SF to be used at a particular cement plant.

An appropriate method has to be found to inject the fuels into the kiln and pre-heater or pre-calciner firing systems.

Methods used for the handling and transport of typical SFs including tyres, tyre chips, PSP, MBM, SLF and solid waste-derived fuels such as Profuel® have to be evaluated to ensure they are appropriate for each cement plant

A system of plant safety interlocks has to be incorporated into control systems at the plants. These are essential to ensure that SFs can only be burned when the kiln is stable and operating with emissions within the permitted ELVs.

Auditable documentation procedures have to be followed to control transport from the fuel blender (SRM) to the cement plant. An example of the duty of care requirements is shown in Annex E. The example given is the procedure for SLF at Cookstown works.

2.9 Alternative uses of materials used as substitute fuels

For a material to be used as a SF, it must not be possible for the SF to be technically or economically recovered or recycled further up the waste hierarchy. The operator is required to demonstrate this in the application to burn SFs. In some situations, there may be alternative uses of the SF which are not available at the time of application, because there is no existing market. However, markets may develop in the future which may change the situation for the SF.

Environmental studies considering alternative uses of SF materials have focused on individual SFs; no studies have made comparisons between SFs. For SLF, tyres and RDF, studies consisted of life cycle assessments which evaluate the environmental burdens of a product, process or activity by identifying and quantifying the energy and materials used and wastes released. The combined impact of these factors is assessed along with opportunities for improvement. As life cycle assessment addresses environmental burdens, it is more suitable for considering effects at a global level, such as global warming and ozone depletion, rather than effects at the site-specific level, such as toxic effects. No life cycle assessments were identified for RFO, MBM and PSP. For these SFs, consideration was given to their alternative uses and the relative positions of these uses in the waste hierarchy.

2.9.1 Secondary liquid fuel

A life cycle assessment of SLF used in cement kilns10 listed high temperature incineration with energy recovery and recycling as alternatives to cement kilns. Recycling involves distilling the SLF waste to recover solvent or another useable product. There are two main groups of products. The first is mixed solvents for general purpose use, often known as thinners, and the second is single solvents such as acetone or toluene. A recovery of approximately 60 to 70 per cent is typical. Distillation to recycle the solvents is carried out wherever it is economically possible. Some of the SLF will be made up of the still bottoms that result from recycling by distillation.

The life cycle assessment found that burning SLF in cement kilns is preferable to disposal by incineration for almost every considered parameter. Parameters included energy, CO2, NOx, SO2 and hydrogen chloride (HCl) emissions, emissions of metals to air, liquid effluent and solid waste. These results were largely due to the fact that SLF replaces the conventional cement kiln fuels of coal and petroleum coke. Possible exceptions include emissions of hydrogen halides, where available data indicate that containment of hydrogen halides is more complete for an incinerator fitted with specific abatement, compared to a cement kiln which relies on the alkalinity of raw materials. Volatile and semi-volatile metals may also follow this pattern.

The analysis of solvent recycling was found to be complex, as the results were different for every solvent compound. However, the following was concluded from the life cycle assessment:

- recycling is environmentally preferable to incineration for almost every considered parameter;

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[10] Environment Agency. *Substitute liquid fuel (SLF) used in cement kilns – Life cycle analysis*. R&D Technical Report P274, 1999.

- recovery of a high percentage of solvent, to leave a dry residue, is environmentally preferable to 60 to 70 per cent recovery with incineration of residues;

- recycling is not necessarily environmentally preferable to the use of SLF in cement kilns, as this varies depending on solvent type, with the comparison between recycling and use of SLF in cement kilns showing trade-offs in some considerations.

- Overall, it was concluded that it was not easy to define wastes which for environmental reasons should be recycled, thus moving their use further up the waste hierarchy, rather than being used as SLF in cement kilns.

2.9.2 Recovered fuel oil

RFO is used as a reductant in steel making or is burnt to recover energy at sites that have PPC permits incorporating requirements of the WID. Cement kilns are amongst these sites. In addition, RFO can be burnt in small waste oil burners which are exempt from the WID. Hence, there is only one alternative use of RFO that lies further up the waste hierarchy compared to use in cement kilns, but this market has only recently emerged.

2.9.3 Tyres

A life cycle assessment of management options for waste tyres[11] listed the following uses of waste tyres as alternatives to combustion in cement kilns:

- export for further use;

- retreading;

- reuse in sea defences;

- reuse in drainage applications;

- recycling to rubber crumb;

- pyrolysis;

- gasification;

- degradation by microwave treatment.

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[11] Environment Agency. *Life cycle assessment of the management options for waste tyres*. R&D Technical Report P1-437/TR, 2004

All of the above options, apart from degradation by microwave treatment, are in use in the UK. These options include treatments that lie further up the waste hierarchy compared to cement kilns. Export for further use accounts for a small percentage of waste tyres and the additional mileage in the country of destination is limited. Retreading of tyres involves removing (buffing off) the remainder of the worn tread, overlaying a new strip of rubber and remoulding. Buffings from this process are incinerated or recycled. Since 2002, retreaded tyres have had to be type approved to ECE Regulation 109, demonstrating the same safety standards as new tyres. Only a small number of tyres are retreaded because of commercial considerations. Reuse in drainage involves the use of shredded tyres for landfill drainage in a modern controlled landfill.

Recycling to rubber crumb involves granulation of the tyres into rubber particles which can then be used as raw material in a variety of applications including sports surfaces, porous hosepipes, rubber boots, carpet backing, road building and as an aggregate replacement in concrete. Of these uses, the manufacture of consumer products was considered in the life cycle assessment, where two pyrolysis processes were considered. In addition to the above uses, consideration was given to the benefits of renewing tyres at an earlier stage in their life, to allow easier retreading or export.

Table 2.19 shows the management options that achieved the best and worst scores for each of the impact categories considered in the life cycle assessment. The results shown in italics in this table should be treated with caution, owing to uncertainties in the methods used for these categories.

Table 2.19: Management options achieving best and worst scores for each of the impact categories

Impact category	Management option achieving best score	Management option achieving worst score
Abiotic depletion	Retreading	Use as drainage fill
Global warming	Retreading	Gasification
Ozone depletion	Retreading	Gasification
Photochemical oxidation	Cement kilns	Use as drainage fill
Acidification	Retreading/cement kilns	Microwave treatment
Eutrophication	Retreading	Microwave treatment
Human toxicity	Cement kilns	Gasification
Freshwater aquatic toxicity	Retreading	Crumbing to flooring
Marine aquatic toxicity	Retreading	Microwave treatment
Terrestrial ecotoxicity	Retreading	Gasification

It was concluded that all waste management options exhibited some benefits compared with ‘do nothing’. In fact export, retreading, use in sea defences and one of the pyrolysis processes provided benefits for all the impact categories. Use in cement kilns provided the best or second best impact score in seven of the 10 impact categories, whilst retreading, which lies further up the waste hierarchy, provided the best or second best score in all impact categories.

In the UK, 25 to 30 per cent of used car tyres and 60 to 65 per cent of commercial tyres are suitable for retreading, but in practice only 20 per cent of used car tyres and 455 commercial tyres are retreaded each year. According to the Used Tyre Working Group, in 2001 UK tyre waste totalled 481,496 tonnes with a recovery rate of just over 60 per cent. The recovery rate includes all collected tyres used for the following: reuse as part worn; retreading; recycling; landfill engineering; and energy recovery.

2.9.4 Refuse-derived fuel

The fraction of municipal solid waste used to produce RDF is generally the non-recyclable residue left after pre-treatment of the waste. However, a study by WRc12 found that this is not always true. For example, if the waste collector is paid to deliver waste which can be used as fuel, and if the sum paid for the waste is greater than the sum that would be derived from recycling, it was concluded that use of the material as fuel is likely to continue. In this situation, waste is being diverted from a use that lies further up the waste hierarchy. There was no mention in the study of the destination for the RDF.

The study by WRc (2003) also involved a life cycle assessment of RDF processed from municipal solid waste. The assessment compared co-incineration in brown coal fired plants, hard coal fired plants and cement works and incineration in municipal waste incinerators. The main conclusions of the assessment were that none of the options was globally advantageous.

2.9.5 Meat and bone meal

Waste arising from the preparation of meat for human consumption from which MBM is derived is Category 3 material under EC Regulation 1774/2002 laying down health rules concerning animal by-products not intended for human consumption. Article 6 specifies that Category 3 material shall be:

- “directly disposed of as waste by incineration in an incineration plant approved in accordance with Article 12;
- processed in a processing plant in accordance with Article 13…and disposed of as waste either by incineration or by co-incineration in an incineration or co-incineration plant approved in accordance with Article 12 or in a landfill approved under Directive 1999/31/EC;
- processed in a processing plant approved in accordance with Article 17;
- transformed in a technical plant approved in accordance with Article 18;
- used as a raw material in a pet food plant approved in accordance with Article 18;
- transformed in a biogas plant or in a composting plant approved in accordance with Article 18;

- in the case of catering waste referred to in paragraph 1(l), transformed in a biogas plant or composted in accordance with rules laid down under the procedure referred to in Article 33(2)…;

- in the case of material of fish origin, ensiled or composted in accordance with rules laid down under the procedure referred to in Article 33(2)."

The above listed items include treatments that lie further up the waste hierarchy compared to use of MBM in cement kilns.

2.9.6 Processed sewage pellets

Clarke[13] lists the following alternatives to cement manufacture for sewage sludge disposal routes employed in the UK in 2004:

- agriculture;
- incineration with energy recovery;
- landfill;
- compost;
- industrial crops;
- land reclamation.

These alternatives include uses that lie further up the waste hierarchy than cement manufacture. The agricultural route involves the use of biosolids as a soil improver and fertiliser, whilst compost involves their use as an alternative to peat products. The industrial crops route also involves their use as a soil improver, whilst land reclamation involves their use to restore derelict land for development, amenity, forestry and wildlife.

However, there are constraints associated with the above-mentioned uses. Along with the presence of high levels of contaminants in the sewage sludge, other constraints include the availability of suitable farmland close to the sewage treatment plant that is not subject to restrictions on land spreading due to the presence of nitrate vulnerable zones.

Research over many years has shown that recycling of biosolids as a soil improver and fertiliser is the best practicable environmental option (BPEO). Some 62 per cent of the 1.3 million tonnes of dry solids produced by England and Wales wastewater companies were used in this way in 2004. In order to support this use, a safe sludge matrix has been agreed with stakeholders, including retailers.

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[12] WRc. *Refuse-derived fuel, current practice and perspectives*. B4-3040/2000/306517/MAR/E3, European Commission – Directorate General Environment, 2003.
[13] Clarke. Growing use for sludge. Water and Wastewater Treatment, 2006.

2.9.7 Conclusions

Studies considering alternative uses of SF materials have focused on individual SFs, so it is not possible to draw overall conclusions on the use of SFs in cement kilns. In addition, life cycle assessments have been undertaken for only a limited number of SFs, with variable results. For SLF, it was concluded that burning in cement kilns is preferable to disposal by incineration for almost every considered parameter. For tyres, retreading (where retreaded tyres demonstrate the same safety standards as new tyres) was found to provide the best or second best score in more impact categories than use in cement kilns, and for RDF none of the considered options was found to be globally advantageous.

3 Analysis of effects of burning substitute fuels in cement and lime kilns

3.1 Effects on cement-making operations

The SFP addresses the requirements for process parameter recording during SF trials. Parameters include process temperatures, fuel quality and firing rates, outputs and clinker chemistry. SF trial reports contain a large amount of supporting process data; however, they do not provide a detailed assessment of the effects of SF burning on kiln performance. Without detailed knowledge of the individual process operations, it is not possible to comment on the process implications of burning SFs on individual plant performance. However, earlier SF studies found that using SFs could reduce kiln capacity. In one case, around 50 per cent of the fuel cost savings from burning SLF was offset by the need to purchase additional imported clinker to compensate for the lower kiln output. The loss of output was related to the moisture content of the SLF, as lower CV/higher moisture content SLF caused a greater loss of capacity. In another case, kiln plant capacity increased by around five per cent after SLF use ceased. A study of the effects of biomass fuel firing showed that a loss in production of around five to seven per cent was expected in a kiln process limited by gas flow considerations.

It is possible to predict several effects of using SFs by employing various modelling techniques (heat and mass balances and power consumption modelling). This approach is recommended at the planning stage to ensure that all costs associated with using SFs are considered. A simplified approach would be as follows:

- quantify SF quality and obtain an ultimate analysis to predict process heat and mass balances;

- predict total stack exit volumes and hence fan power costs. If the process has a limit on the fan capacity, the burning of higher moisture and lower CV fuel may reduce kiln capacity. A financial assessment may then have to consider the value of any lost capacity;

- determine the sulphur balances to predict effects on clinker sulphur trioxide (SO3) chemistry and hence predict cement grindability (the higher the cement grindability, the harder it is to grind). Feed this information into the prediction of overall energy costs, noting that reduced fuel mill run time will usually offset any additional SF processing power costs;

- consider the effects of changes in clinker chemistry on cement quality such as strength development, P2O5 and chloride content, and target cement surface area requirements;

- consider possible effects on kiln bypass ratio which directly relate to dust loss and additional fuel and power costs. Bypass dust represents a disposal issue, unless it can be used in the cement mills as material addition to cement.

No assessment could be made in this study of the overall effects of burning SFs on kiln output or fuel consumption. Assessment of suitable SFs is both environmentally and financially based. Any financial appraisal needs to take into account the above factors, as additional operating costs (plus capital charges for new equipment) may offset the benefits from lower purchased fuel costs. It is not possible to make a detailed assessment of the financial benefits of using different SFs.

3.2 Effects on the local environment

In order to demonstrate that use of SFs in cement and lime kilns is satisfactory, the operator needs to show that BAT is being applied to the burning of an SF and that ELVs specified in the WID are met. In addition, the requirements of the SFP need to be met, including the need for a trial operation with the SF and specification of CSFs that have to be met by the trial. These CSFs are the benchmarks by which a SF is judged. Probably the most significant of the CSFs is the demonstration of no net detriment to the local environment from SF burning. The assessment used here is based on the Environment Agency's H1 method and takes into account other benchmark criteria to protect the environment. Further information on the H1 method can be found in Annex C.

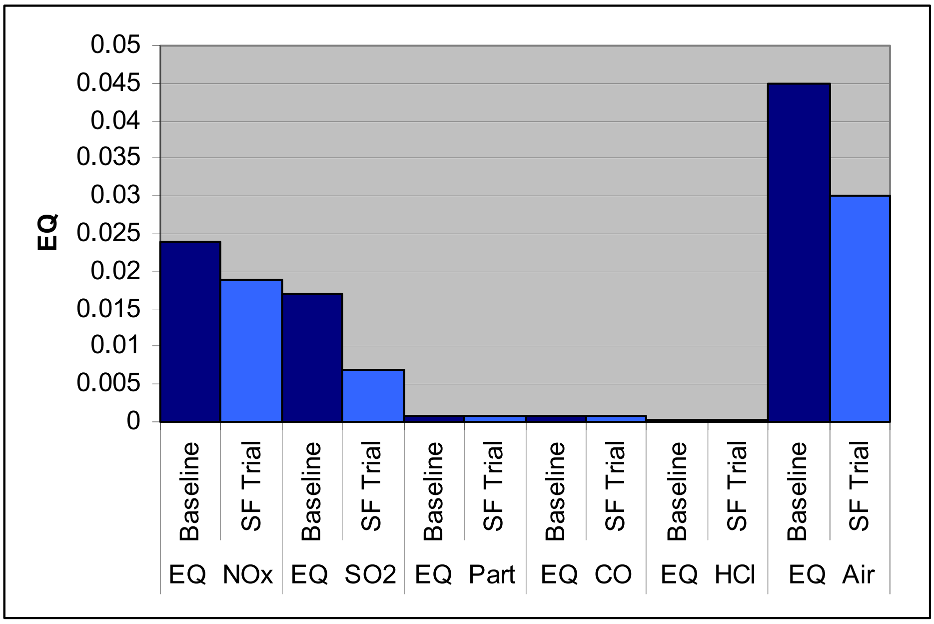
In order to demonstrate no net detriment to the local environment, the operator has first to consider the environmental impact under baseline conditions, which may involve operating with conventional fuel alone or with conventional fuel plus an existing SF. This environmental impact is then compared with the impact of using the new fuel at the maximum proposed substitution rate. No net environmental detriment can be demonstrated providing there is no overall increase in environmental impact from using the new fuel compared with the baseline operation.

As the major environmental impact of cement plants arises from air emissions, these form the focus of the demonstration of no net environmental detriment. The environmental quotient (EQ) for each substance emitted to air is obtained by normalising the long-term process contribution (PCair long-term) for the substance against the appropriate environmental benchmark (UK AQS) objective or environmental assessment level (EAL). The PC is the ground level concentration of the substance that arises from emission of that substance. EQs for all the substances are then summed to provide the total EQ for air (EQair), which represents the total impact of emissions to air. Annex D provides a collation of data on the environmental effects of emissions from cement kilns.

3.2.1 Secondary liquid fuel and Cemfuel®

Figure 3.1 illustrates the process of proving no net environmental detriment, by comparing baseline EQs and SF trial EQs for SLF burning at South Ferriby.

Figure 3.1: Comparison of baseline EQs and SF trial EQs for SLF burning at South Ferriby



For NOx, SO2 and particulates for South Ferriby (Figure 3.1), the baseline EQ is greater than the SF trial EQ, indicating that the burning of SLF at South Ferriby decreases ground level concentrations of these substances. The results for NOx and SO2 for South Ferriby agree with results shown in Annex D for NOx and SO2 for SLF and Cemfuel® burning, as there is an improvement in EQNOx and EQSO2 in all cases shown in Annex D. A reduction in kiln flame temperature arising from the water content of SLF may be one of the effects that leads to the NOx reduction associated with SLF burning.

The results outlined in Annex D for SLF and Cemfuel® burning show both improvements and a worsening in the EQpart. Particulate emissions depend on the physical condition of the main dust collector for the cement kiln, whether it is an ESP or a baghouse. Factors such as the level of leaking air and efficiency of cyclone collection will affect gas volume and dust duty on these dust collectors. ESP performance is sensitive to factors such as dust resistivity, which is a function of the operating temperature and gas humidity. There are no supporting data to relate the burning of SFs to dust resistivity, although dust chemistry is usually determined to obtain chemical variations. Hence, the fuel mix burned is not expected to have any major influence on the collection efficiency and hence the particulate emissions. This is reflected in the variable results shown in Annex D for particulates for SLF and Cemfuel® burning.

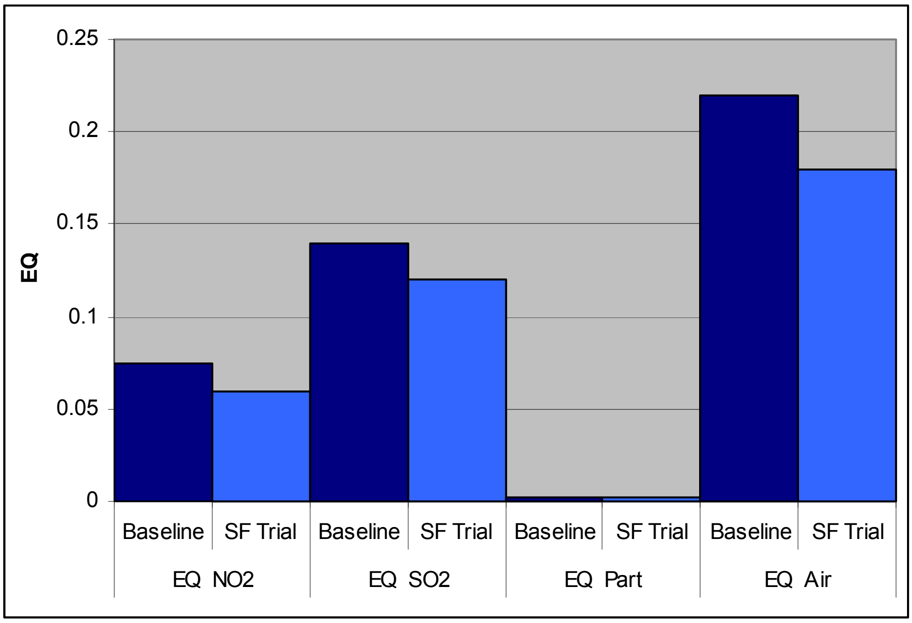
For CO and HCl for South Ferriby (Figure 3.1), the baseline EQ is less than the SF trial EQ, indicating that the burning of SLF at South Ferriby increases the ground level concentrations of these substances. The results shown in Annex D for CO and HCl for SLF and Cemfuel® burning show both an improvement and worsening in EQCO and EQHCl. Both CO and HCl emissions are independent of SF burning, which is reflected in the variable results shown in Annex D for CO and HCl.

Figure 3.1 also shows the baseline and SF trial EQair. The baseline EQair is greater than the SF trial EQair, indicating that the burning of SLF at South Ferriby reduces the total impact of emissions to air. The improvement in EQair demonstrates no net environmental detriment arising from the burning of SLF at South Ferriby. This result agrees with all the results shown in Annex D for local effects to air for SLF and Cemfuel® burning, as there is an improvement in EQair in all cases shown in Annex D.

3.2.2 Tyres

Figure 3.2 further illustrates the process of demonstrating no net environmental detriment, by comparing baseline and SF trial EQs for tyre burning at Dunbar.

Figure 3.2: Comparison of baseline and SF trial EQs for tyre burning at Dunbar



For nitrogen dioxide (NO2), SO2 and particulates for Dunbar (Figure 3.2), the baseline EQ is greater than the SF trial EQ, indicating that the burning of tyres at Dunbar decreases ground level concentrations of these substances. The result for NO2 agrees with the results shown in Annex D for NO2 for tyre burning, as there is an improvement in EQNO2 in all cases shown in Annex D.

SO2results given in Annex D for tyre burning show both an improvement and deterioration in EQSO2. Evidence from the raw material analysis suggests that changes in the raw material pyritic sulphur content is a major factor in SO2 emissions from cement plants. A change in the sulphide content of raw material during either baseline or SF trial periods can generate misleading results. The only way to correct the results is to normalise the test data and use a common background level of sulphide content in the raw material. This involves applying the formulae that relate the SO2 emission to kiln feed sulphur content.

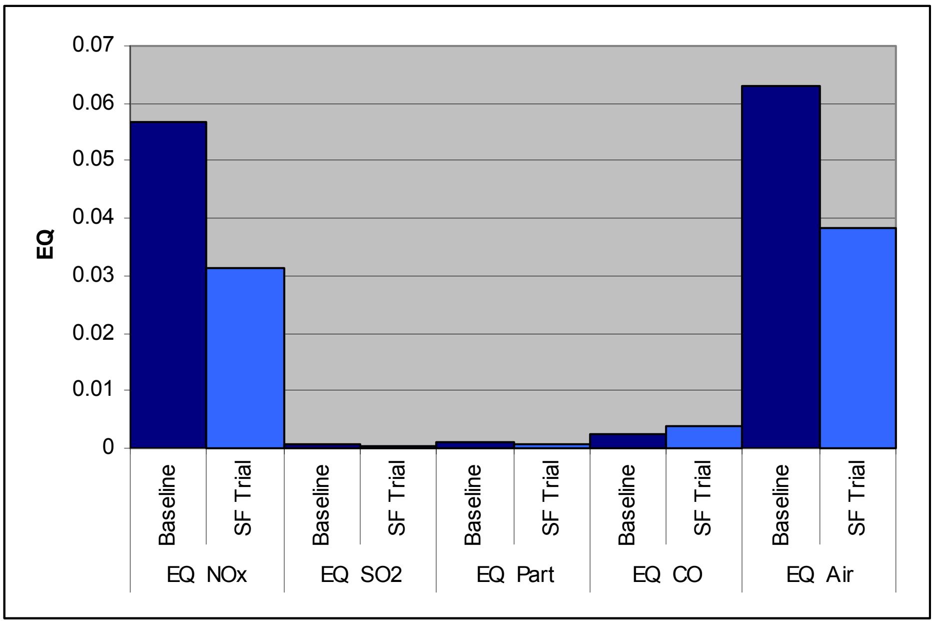
The results given in Annex D for particulates for tyre burning show both improvements and a worsening in EQpart. The reasons for these variable results for particulates have already been discussed.

Figure 3.2 also shows the baseline and SF trial EQair. The baseline EQair is greater than the SF trial EQair, indicating that the burning of tyres at Dunbar reduces the total impact of emissions to air. The improvement in EQair demonstrates no net environmental detriment from the burning of tyres at Dunbar. The result for total impact of emissions to air agrees with all but one of the results shown in Annex D for local effects to air for tyre burning, as there is an improvement in EQair in all but one case shown in Annex D. Even in this case, the change amounts to only a 2.4 per cent worsening.

3.2.3 Refuse-derived fuel

Figure 3.3 further illustrates the process of demonstrating no net environmental detriment, by comparing baseline and SF trial EQs for RDF burning at Ketton.

Figure 3.3: Comparison of baseline and SF trial EQs for RDF burning at Ketton



For NOx, SO2 and particulates for Ketton (Figure 3.3), the baseline EQ is greater than the SF trial EQ, indicating that the burning of RDF at Ketton decreases ground level concentrations of these substances. For CO, the baseline EQ is greater than the SF trial EQ, indicating that RDF burning here increases the ground level concentration of this substance. Figure 3.3 also shows the baseline and SF trial EQair. The baseline EQair is greater than the SF trial EQair, indicating that the burning of RDF at Ketton reduces the total impact arising from emissions to air. The improvement in EQair demonstrates no net environmental detriment from RDF burning at Ketton.

3.3 Effects of Burning Substitute Fuels on Emissions to Air from Lime Kilns

Since SFs are not widely used in lime kilns, limited data are available on SF trials. Available data on SLF burning at the Whitwell works showed that NOX reduction was related to the quantity of SLF burned. The Thrislington works also burns SLF and reductions in NOx were also found here. The Atkins study3 (2005) notes that SDL found that the use of SLF resulted in NOx reductions of around 20 to 40 per cent.

3.3.1 Effects of Modernisation on Emissions to Air from Cement Kilns

Modernisation of the cement industry in the UK means that older wet process kilns will continue to be replaced by modern pre-calciner kilns which use the latest BAT for primary pollution control. Emissions reductions achieved by plant modernisation outweigh any benefits achieved by using SFs alone. Modern kiln designs can be adapted more readily to reduce potential emissions. An example of this is Rugby works kiln, where clay is injected into the calciner to reduce SO2 emissions. Another example is Padeswood works, where potential VOC and CO emissions are reduced by burning the fuel bearing shale in the calciner. Reductions claimed for the Padeswood kiln were as follows: dioxins and furans by 89%; particulates by 33%; NOx by 53%; SO2 by 90% and heavy metals by 63%. Modernisation of the Tunstead works generated the following reductions: SO2 by 67% and particulates by 70%. This clearly demonstrates the environmental benefits of cement plant modernisation using the latest pollution abatement techniques.

Following detailed discussion with the UK cement industry, the Environment Agency published a report in November 2005, Improving environmental performance – A sector plan for the cement industry. The plan forms a framework of agreed national environmental objectives and priorities for the sector over the next five to ten years.

Nine objectives have been set up to improve environmental performance. Objectives directly relevant to this report are discussed below.

The UK cement industry has continued to replace both raw materials and fossil fuels with waste-derived substitutes. In 2005, 4.9 per cent of raw materials and 14.3 per cent of fossil fuels were replaced by waste materials, adding up to over one million tonnes of waste used in the year. Of the 15 cement-manufacturing plants covered by this report, nine were using at least one alternative fuel either permanently or under trial during 2005. The performance indicator table below shows a 2.5 per cent reduction in the use of virgin raw materials per tonne of cement produced since the 1998 baseline with, on the same basis, a 22.7 per cent drop in fossil fuels.

Table 3.1: Performance indicators - Reduced consumption of natural resources per tonne of cement manufactured

		Base	Actual	Targets	
	Units	1998	2005	2006	2010
Use of natural raw materials per tonne of PCe manufactured [1]	kg/te PCe	1,468	1,437	1,428	1,413
Use of fossil fuels for primary energy per tonne of PCe manufactured	kWh/te PCe	1,103	853	973	764
[1] kg/te PCe is kilograms per tonne of Portland cement equivalent					

Carbon dioxide (CO2), oxides of nitrogen (NOx), sulphur dioxide (SO2) and dust remain the most significant sources of emissions from cement manufacturing. All emissions are falling as a result of investment in abatement technology and more modern plants that, in turn, allow closure of older, less efficient operations. For example, Castle Cement commissioned a new £60 million kiln at its Padeswood works in North Wales. Its more efficient dry process kiln operation has allowed the closure of two wet kilns and a dry one at that location, along with two older kilns at Clitheroe in Lancashire. The overall effect is a 17.5 per cent reduction in CO2 emissions across the company's operations. Lafarge Cement has also invested heavily in environmental control. At its Dunbar works in Scotland, the company has installed a £20 million gas scrubbing system that cuts emissions of both sulphur dioxide and dust by half. Cemex announced a £6.5 million investment in bag filters at its Rugby plant, to reduce dust emissions by up to 40 per cent; it should be operational early in 2007. As shown in the performance indicator table below, none of the 15 manufacturing plants requires further action to reduce local environmental impacts identified by the Environment Agency, although all companies will continue to work to reduce further their overall environmental impact. With this in mind, it is gratifying to note that the industry's total environmental burden to air (see table footnote) had decreased by 35 per cent by the end of 2005, compared to the 1998 level.

Table 3.2: Performance indicators - Reduced emissions from cement manufacturing

		Base	Actual	Targets	
	Units	1998	2005	2006	2010
Number of sites requiring action to reduce local environmental impacts [2]	Number	2	2	2	0
Dust emissions to air per tonne of PCe manufactured [3]	kg/te PCe	0.33	0.13	0.20	0.15
NOx emissions to air per tonne of PCe manufactured	kg/te PCe	3.34	2.77	2.80	2.50
SO2 emissions to air per tonne of PCe manufactured	kg/te PCe	2.56	1.37	1.50	1.10
Total environmental burden to air [4]	Burden value	1,807	1,157	1,237	1,054

[2] Number and proportion of sites where pollution reduction is required via a PPC improvement programme to satisfy an existing statutory local environment action plan. This assessment includes the impact of fugitive dust emissions.

[3] Measured as total particulate. This comprises all particle fractions including PM10.

[4] Mass divided by environmental assessment level for oxides of nitrogen, sulphur dioxide and particulates.

The UK cement industry is playing an important role in minimising some of the country's waste disposal by processing selected wastes into alternative kiln fuels. The use of these materials brings other environmental benefits such as reduced emissions of air pollutants such as oxides of nitrogen. Cement kilns can safely employ selected waste-derived fuels for several reasons:

- raw material temperatures reach over 1,450oC;
- flame temperature inside the kiln is over 2,000oC;
- gas residence times are over four seconds;
- the turbulent atmosphere within a kiln ensures good mixing;
- the alkali atmosphere within the kiln prevents acid gas emissions;
- ash from combustion is absorbed into the cement.

In 2005, all four BCA members introduced programmes to ensure compliance with the EU WID, which applies to all plants that recover energy from waste or incinerate waste for disposal. The most recent additions to the waste products used permanently by the industry are MBM at Castle's Ribblesdale works in Lancashire and sewage sludge at Lafarge's operation at Cauldon.

Table 3.3: Performance indicators - Optimised sustainable use of waste from other industries or sources

		Base	Actual	Targets	
	Units	1998	2005	2006	2010
Mass of waste recovered as fuel per tonne of PCe manufactured	kg/te PCe	9.64	23.14	14.00	21.00
Mass of waste recovered as raw materials per tonne of PCe manufactured	kg/te PCe	25.70	73.94	50.00	100
Proportion of fuel comprising waste material	mass%	5.7	14.28	10.00	15.00
Proportion of raw materials comprising waste material	mass %	1.7	4.89	4.00	8.00

3.3.2 Waste Incineration Directive and its Implications for Cement Kilns

The Waste Incineration Directive sets emission limit values for incineration and co-incineration of all wastes. It excludes plants that incinerate only certain types of waste from its scope. WID requires continuous measurements of several emission components, and dioxin and heavy metal measurements twice a year.

The purpose of this section is to describe the implications of the WID on the burning of SFs in cement kilns. The following areas are addressed:

- Derogations may be applied to ELVs for SO2 and VOCs, owing to the fact that SO2 emissions primarily relate to the pyritic sulphur content of raw materials and VOC emissions are generally derived from the organic carbon content of raw materials; therefore, neither of these is influenced by fuel characteristics. Applications for permit variations to bring in the WID requirements contain supporting information to demonstrate the formation of SO2 emissions, plus information on the combustion characteristics of VOCs.

- Derogations applied to NOx relate to the processes used at each plant and will vary according to the technology used, with wet process kilns having a higher ELV that dry process kilns. In addition, there is a timescale for reducing NOx ELVs, plus higher ELVs apply in the case of no SF burning.

- Some factors can influence HCl emissions.

- A limit of 40 per cent hazardous waste for co-incineration in cement kilns is imposed by the WID. This restricts applications to burn SLF and there are related process parameters which may impose a limit on the maximum SLF thermal substitution, such as moisture content, effect on flame temperature and chloride input.

- A major impact of the WID on NOx reduction has been the implementation of new SNCR systems at several cement works.

Derogations can be required for some business practicalities. Cement plants are built next to quarries for financial reasons, owing to the large amount of raw material that needs to be transported from the quarry to the plant. When the feasibility of a new cement plant is assessed, the normal requirements are for at least 25 years or more of reserves, preferably 50 years or more. Most UK cement plants were built over thirty years ago when environmental standards were less well developed.

Carbon monoxide, volatile organic compounds and sulphur dioxide emissions

The WID specifies that the ELV for CO can be set by the regulator. However, Sector Guidance IPPC S3.01[14] includes under Section 3.6 the statement that "whilst levels of 300-500 mg/m^3 (CO) are achievable in some cases, primary control to minimise CO may prejudice other related releases, for example NOX".

Although ELVs for SO2 and VOCs are specified in the WID, the regulator can set exemptions to these values where SO2 and VOCs do not result from the incineration of waste. Pyritic sulphur in raw material for cement manufacture leads to emissions of SO2, hence in these cases the SO2 ELV is eligible for derogation. Organic carbon in the raw material may volatilise in the pre-heater and leave as oxides of carbon, with some unoxidised VOCs. The test data reported in applications for permit variations to bring in the WID requirements show that some 97 to 99 per cent of the carbon content in raw feed VOCs is converted to oxides of carbon. Data show that the VOC emission is generally derived from the organic carbon content of raw materials and therefore the VOC ELV is eligible for derogation. Examples of derogations for SO2 and VOCs are shown in Table 3.4, obtained from recent permit variations. Applications for these variations include test data to support derogations for SO2 and VOCs.

[14] Environment Agency. *Integrated Pollution Prevention and Control (IPPC) guidance for the cement and lime sector.* Sector Guidance Note IPPC S3.01, 2001.

Table 3-4: Derogations for SO2 and VOC emissions in WID variation applications

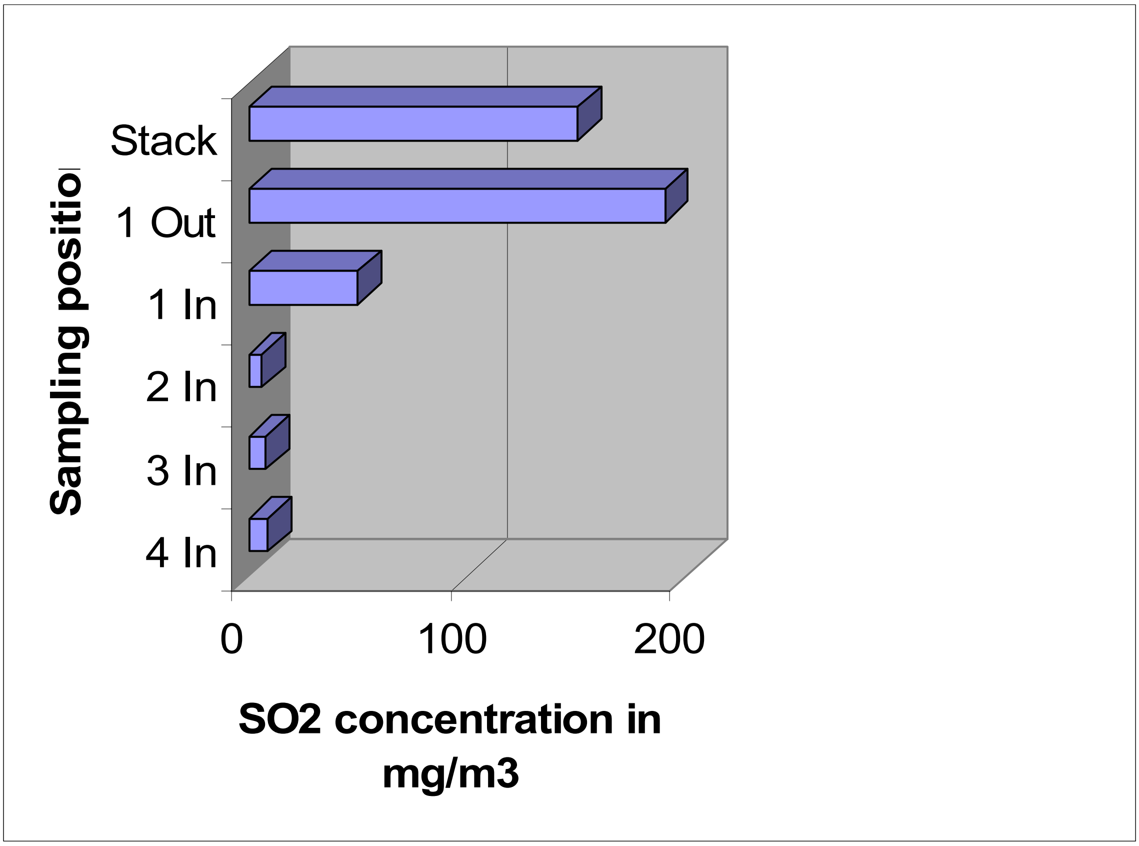
Cement works	Increase in SO2 between the kiln exit and the kiln stack inlet	Increase in SO2 between the Stage X1 cyclone inlet and the kiln stack inlet	Derogation applied for SO2	Derogation applied for VOC (TOC2)
	mg/m^3	mg/m^3	mg/m^3	mg/m^3
Aberthaw	141		1,200	75
Cauldon		159 (Stage 4 to stack)	750	200
Dunbar	[3]		4,400 [4]	200
Hope	546		1,760	150
Ribblesdale		2,490 [5] (Stage 3 to stack)	2205	110
Ketton	[6]		200	110
Padeswood	[6]		200	60
Rugby	[6]		250	
Derogations -Lepol and Wet Kilns				
Barrington		Not applicable	2,300	
South Ferriby		Not applicable	1,750	
Westbury		Not applicable	1,000	150

Notes:

1. Stage number, as specified in the table.
2. Total organic carbon.
3. Although the Dunbar application for variation to bring in the WID requirements does not show the variations in SO2 throughout the pre-calciner process, it uses data from Cauldon works.
4. The derogation for SO2 at Dunbar works is applicable until the new SO2 scrubber is installed.
5. Ribblesdale SO2 concentrations are shown as 2,490 mg/m3 leaving the pre-heater, but these are reduced to below 220 mg/m3 at the stack by the action of the SO2 scrubber.
6. The ELVs applied to Ketton, Padeswood and Rugby works do not include a similar analysis to show the basis for the TOC and SO2 derogation, but these values must be based upon knowledge of the raw material characteristics. Ketton application for variation to bring in the WID requirements uses data from the Ribblesdale tests for SO2 and TOC. The ELV for SO2 is the same as the minimum Sector Guidance value (200-400 mg/m3). The Ketton WID variation application notes that "with low sulphide raw materials a long-term mean emission level of less than 200 mg/Nm3 is expected".

The effects of pyritic sulphur in raw materials are illustrated in Figure 3.4, which shows the manner in which the SO2 is driven off in the upper cyclone stages. The data shown here are taken from the Aberthaw works pre-heater survey and were used to justify the derogation for SO2 that is listed above. They show that the SO2 is driven off around the area of the stage 1 cyclone, as demonstrated by the increased SO2 in the stage 1 exit gases.

Figure 3.4: Aberthaw works pre-heater survey for SO2 emissions



3.3.3 Emission limit values for oxides of nitrogen

The NOX ELVs applied to cement plants are as follows:

- existing plants: 800 mg/m^3;
- new plants: 500 mg/m^3;
- existing wet plants and plants burning less than three tonnes per hour waste, until 31 December 2007: 1,200 mg/m^3;
- existing wet plants and plants burning less than three tonnes per hour waste, from 1 January 2008: 800 mg/m^3.

As an example, Cemex has been granted derogation for NOx emissions from a wet kiln at the Barrington works, as shown in Table 3.5. A higher ELV of 2,500 mg/m^3 with no SF firing is also shown in Table 3.5.

Table 3.5: WID variation derogation for NOx for Barrington works

Parameter	Daily average ELV by CEM	Operating case
Oxides of nitrogen (NO and NO2 expressed as NO2)	1,200 mg/m3 daily average	Limit until 31/12/07
Oxides of nitrogen (NO and NO2 expressed as NO2)	800 mg/m3 daily average	Limit from 01/01/08
Oxides of nitrogen (NO and NO2 expressed as NO2)[1]	2,500 mg/m3 daily average	No SF firing

Notes:

1. This limit only applies when:
   - no SFs are burned during the day;
   - the raw mill is off-line;
   - the kiln is in start-up mode;
   - the SF plant is undergoing maintenance;
   - the operator is required, under the terms of this permit, to cease burning SFs;
   - the kiln is operated for no more than 107 days per year; this figure is to be reviewed annually.

3.3.4 Emission limit values for hydrogen chloride

Based on the review of permit variations to bring in the requirements of the WID, HCl ELVs for cement plants depend on the use of SFs. Typical values taken from recent WID applications include:

- Cauldon works - no limit for HCl is specified when SFs are not used; with SF firing, the HCl limit is 10 mg/m3;

- Barrington works - a limit of 40 mg/m3 for HCl is specified when SFs are not used; with SF firing, the HCl limit is 10 mg/m3.

However, the above limits do not reflect operational experience. Depending on kiln type, HCl emissions can be influenced by operational aspects other than chloride content of the fuel; for example, if the raw mill is off line for maintenance, then HCl is no longer absorbed in the raw feed and this will result in elevated emissions. In these cases, the Environment Agency has granted a separate HCl ELV to cover unavoidable operational circumstances.

The explanation for these discrepancies is that most of the test data provided in applications for permit variations derive from extractive sampling and therefore do not indicate process trends. This means that the reasons for variations in HCl emissions and the influence of raw materials on these emissions are not well documented. This situation has now changed with the introduction of CEMs. A more detailed study using data from the CEMs would be required to consider the factors affecting HCl emissions.

3.3.5 Influence of WID on levels of substitute fuels used in the cement industry

The WID and its predecessor, the Hazardous Waste Incineration Directive, set constraints on the amount of hazardous waste that can be burned in cement kilns. If more than 40 per cent hazardous waste by thermal substitution is burned in the cement plant, the ELVs for incineration plants burning hazardous waste need to be complied with. Operators of cement plants have chosen not to go above the 40 per cent level. There are, however, derogations for some hazardous wastes such as combustible liquid wastes, including waste oils as defined in Article 1 of Council Directive 75/439/EEC of 16 June 1975 on the disposal of waste oils, providing they meet criteria specified in the WID. Also included are combustible liquid wastes which cannot cause, in the flue gas directly resulting from their combustion, emissions other than those from gasoil as defined in Article 1(1) of Directive 93/12/EEC of 23 March 1993 relating to the sulphur content of certain liquid fuels. RFO is a hazardous waste that qualifies for derogation and thus the 40 per cent limit does not apply to RFO.

The 40 per cent limit on hazardous waste (SLF) burning does not necessarily apply outside Europe. For example, in the US two recent pre-calciner kiln plants (one built and one under construction) have replaced wet process kilns. The wet kilns burned SLF for several years. The new kiln design includes a 'hotspot' calciner vessel which operates with a high temperature zone to maximise the burnout of the SLF. In this case, the system is designed to run with up to 100 per cent calciner fuel as SLF, equivalent to a thermal substitution rate of around 60 per cent. Strict operating regimes are reinforced to suit the level of SLF burning.

Tighter limits for particulates, CO, SO2 and NOX for incineration plants specified by the WID would require significant modifications to existing cement plants if they were also to meet these limits. In this situation, any benefits of lower operating costs from the use of SFs would be likely to be outweighed by higher capital as well as operating costs arising from process modifications.

Current technology does not make the design of a cement plant for 100 per cent SF use feasible. However, the policy of major cement companies across the world is to move towards zero fuel costs, for example by introducing the maximum possible amount of SF where the company receives a positive gate revenue for taking waste products from other industries. In designing a cement plant to run on 100 per cent SLF, the following problems would be encountered due to the characteristics of the SF:

- relatively high moisture content, which may help reduce NOX but could adversely affect the kiln capacity;
- as the chlorine content is typically 1.5 to 2.5 per cent, higher SLF use may entail the need for a kiln bypass system with a higher operating cost. This need would also depend on total chloride input from fuels and raw material;
- problems with blending different SFs and maintaining a quality supply for operational stability.

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In the case of co-incineration of untreated mixed municipal waste, the ELVs that apply are those in Annex V (incineration plants). The definition of untreated mixed municipal waste is as follows:

- waste from households as well as commercial, industrial and institutional waste, which because of its nature and composition is similar to waste from households, but excluding fractions indicated in the Annex to Decision 94/3/EC[15] under heading 20 01 that are collected separately at source and excluding other wastes indicated under heading 20 02 of that Annex which are "wastes from the preparation and processing of meat, fish and other foods of animal origin" (see the European Waste Catalogue for further information on this waste code).

Untreated MSW is not considered a suitable SF for use in cement kilns, due to its high variability and high moisture content. However, RDF is a suitable fuel and is finding increased use in various forms. The provisions to apply Annex V ELVs are not appropriate in this case provided that the fuel, of RDF type, is a 'treated' waste. The cement making process requires a processed RDF in order to avoid the following:

- process instability and variability problems;
- reduced clinker output and higher overall fuel consumption due to higher waste gas heat losses;
- cement quality variability problems;
- variable or high SF moisture content causing burning problems due to variable or low flame temperature;
- the consequent risk of variable emission levels.
- Permit variations to bring in WID requirements and use of selective non-catalytic reduction in cement kilns

WID ELVs for NOX are restrictive and most older cement plants have had to invest in abatement equipment to comply with these limits. Some plants have been granted time-limited derogations as allowed by the WID on the basis of technology (wet kilns) or limited waste throughput. SNCR, which is part of a BAT consideration for controlling NOx emissions, has been installed at most plants. Castle Cement advised that they were due to test the use of SNCR with their low NOX calciner design. However, Barrington works is relying on a combination of the NOx-reducing effect of SLF burning with installation of a low NOx burner to meet its derogated limit.

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[15] European Commission Decision 94/3/EC of 20 December 1993 establishing a list of wastes pursuant to Article 1a of Council Directive 75/442/EEC on waste (OJ L 5, 7.1.1994, p.15).

The use of SFs to reduce NOX emissions should be part of an overall strategy and BAT assessment, taking into account the benefits of SNCR. Another factor is cost; SNCR is quoted as costing around £0.50 per tonne of cement. If the amount of NOX generated can be minimised then this should, in theory, reduce the amount of reagent required. Castle Cement recently reported that the installation of SNCR at the Ketton works was budgeted at £620,000.

At the time of writing, it was not possible to judge the efficiency of using multi-stage combustion (MSC) techniques alone, as data were not available. A review of data from recent US kilns using MSC showed that the efficiency of this technique was related to factors such as the fuel vinyl chloride monomer (VCM) content and the combinability characteristics of the raw mix. Hence, the availability of SNCR as a backup to MSC is desirable. Limited literature was available to show how MSC and SNCR work together, but it is hoped that this will be proven by tests to be conducted at the Padeswood works.

3.3.6 Conclusions

An adverse effect on cement-making operations from the use of SFs is a reduction in kiln capacity. However, SF trial reports have not highlighted any major changes in kiln performance. Data on effects on the environment provided in trial reports indicate that the burning of SLF, Cemfuel®, tyres or RDF can reduce the total impacts of emissions to air. For lime kilns, there are limited data relating to effects on the environment, but SLF burning appears to reduce NOx emissions.

Under the WID, cement kilns have been granted derogations for ELVs for SO2 and VOCs, where it has been shown that emissions of these substances do not result from the incineration of waste, but arise from raw materials. Derogations have also been granted for ELVs for NOx, with values assigned depending on the technology used at each plant. A timescale has been set for reducing these ELVs. Higher ELVs have been assigned for operations with no SF burning. In the case of HCl, derogations have been granted for unavoidable operational circumstances. Operators of cement plants have chosen not to go above the 40 per cent level for thermal substitution of hazardous waste; above this limit, different emission limits apply. SCNR, which is part of a BAT consideration for controlling NOx emissions, has been installed in most cement plants as a consequence of the introduction of the WID.

4 Impact assessment

4.1 Air Quality

4.1.1 Background to regulation

In common with many industrial processes, cement production entails atmospheric discharges. The main releases to air arise from the kiln stage via kiln exhaust gases, clinker cooler exhaust and any bypass gases. Some substances in these emissions have the potential to cause adverse health or environmental effects, either at high concentrations for short periods (such as an hour) or at low concentrations over long periods of time (such as a year).

The Environment Agency regulates stack height and sets pollutant emission limits within PPC permit conditions to ensure that concentrations of pollutants at ground level do not breach UK AQS objectives or EALs. AQS objectives relevant to this study are presented in Table 4.1. There are also objectives for the protection of vegetation which are not prescribed in regulations, as this is a national rather than local issue. AQS objectives cover the 'classic' air pollutants, NO2[16,] SO2 and particulate matter with an aerodynamic diameter of less than 10 microns (PM10) as well as CO. For other substances without AQS objectives, such as metals and organic compounds, the Environment Agency specifies environmental benchmarks in terms of long-term and short-term concentrations (EALs) set for the protection of human health[17]. In addition, there is a WHO annual mean guideline for SO2 of 50 µg/m^3.

[16] Oxides of nitrogen are discharged from the cement kiln stack mainly in the form of nitric oxide (NO), with traces of NO_2. NO is slowly oxidised in the atmosphere to NO_2. NO_2 has the potential to affect respiratory function in high concentrations and hence this is the substance regulated in the AQS.

[17] Environment Agency. *Horizontal Guidance Note IPPC H1. Environmental Assessment and Appraisal of BAT.* 2002.

Table 4.1: UK Air Quality Strategy objectives

Pollutant	Criteria	Value µg/m3	Target date
Nitrogen dioxide (NO2)	Annual mean	40	31 December 2005
	One-hour mean (not to be exceeded more than 18 times a year)	200	31 December 2005
Sulphur dioxide (SO2)	99.9th percentile of 15-minute means	266	31 December 2005
	One-hour mean not to be exceeded more than 24 times per year (99.73th percentile)	350	31 December 2004
	24-hour mean not to be exceeded more than three times per year (99.2th percentile)	125	31 December 2004
Particulate matter (PM10)	24-hour mean (not to be exceeded more than 35 times a year) [1]	50	31 December 2004
	Annual mean [1]	40	31 December 2004
	24-hour mean (not to be exceeded more than seven times a year) [2,3]	50	31 December 2010
	Annual mean [2,3]	20	31 December 2010
Carbon monoxide (CO)	Maximum daily running eight-hour mean	10,000	31 December 2003

Notes:
1. Measured gravimetrically.
2. Provisional and will not be included in the regulations in the short term
3. England (apart from London).

As part of demonstrating that requirements of the SFP are met, operators may use dispersion modelling to show the potential effects on ground level pollution concentrations. Ambient air monitoring is not normally an Environment Agency requirement for the purposes of predictive modelling at the application stage. The normal approach is to use information on ambient air concentrations that can be identified (for example, from local authority monitoring stations). Selection of a monitoring site location from which to obtain the data often presents both technical and practical difficulties.

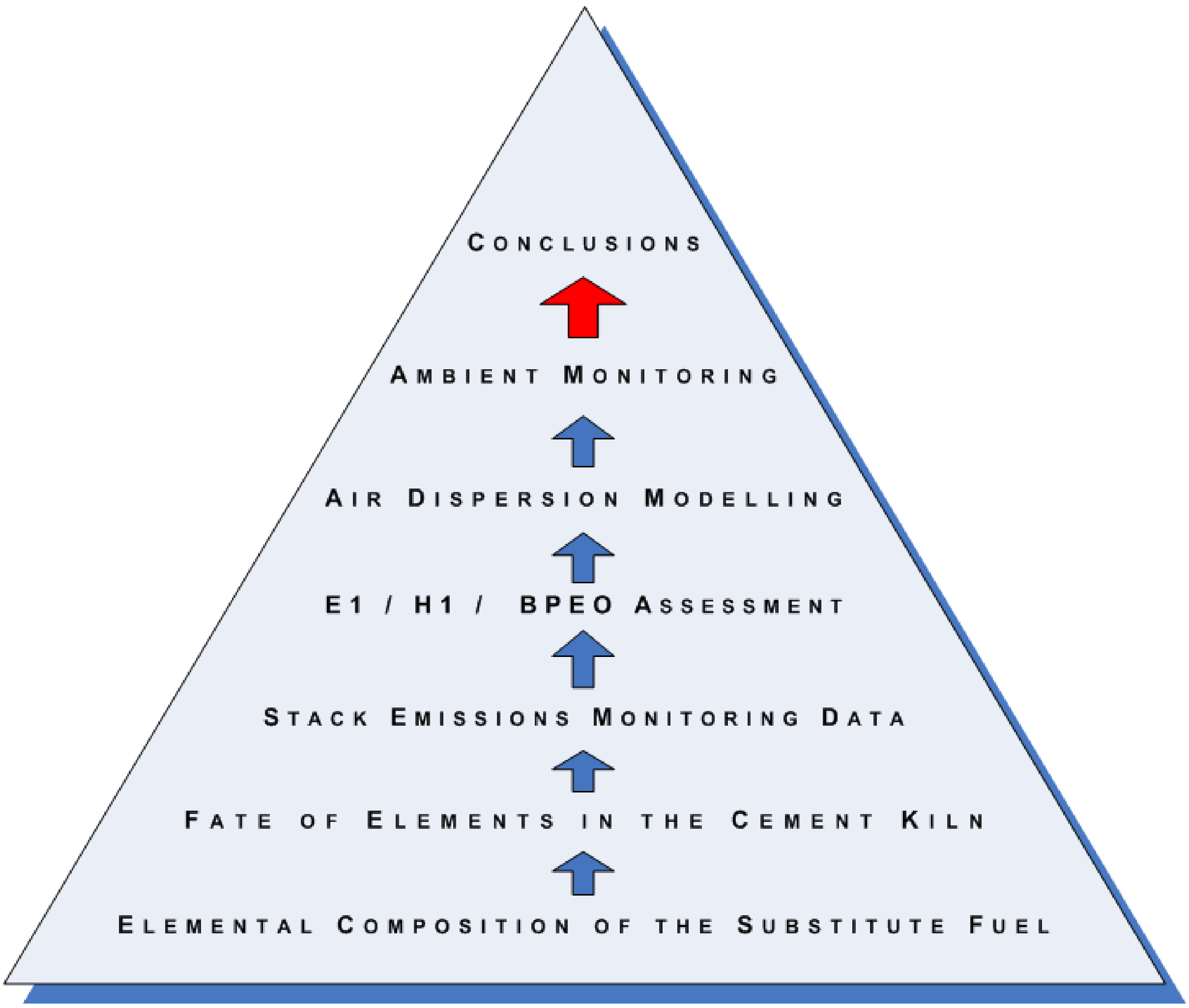
All local authorities are required by Part IV of the Environment Act 1995 to review air quality in their area. They must assess both the present and likely future air quality against objectives set out in the AQS. Where the objectives defined in regulations are not likely to be achieved in all relevant locations, the authority must designate these areas as Air Quality Management Areas (AQMAs) by order and develop an action plan to improve air quality. Relevant locations include areas outside buildings or man-made structures above or below ground level and where members of the public are regularly present and are likely to be exposed over the averaging time of the objective.

4.1.2 Approach to assessment of effects

In support of applications, operators may use the Environment Agency's H1 assessment tool or more sophisticated dispersion modelling techniques to predict ground level concentrations. In many instances, it is evident that a change in fuel use and a consequent minor change in emission rates would not cause any measurable difference in ambient air quality. Because the cement works only makes a small contribution to ambient pollution levels in the first place, any incremental changes arising from the use of SFs will be even more difficult to distinguish. In fact, ambient monitoring has only been carried out to date at five sites: Ribblesdale; Padeswood; Westbury; Barrington and Rugby. In some cases, monitoring was carried out to address public concerns relating to normal operation and not necessarily to address emissions during SF trials.

Air dispersion modelling studies of several sites and fuel types were reviewed for this project. However, in many cases only information on changes in stack emissions, elemental composition of fuels and general information on element fate in the cement-making process was assessed. It was thus necessary to apply an information hierarchy and use read-across techniques to draw conclusions on the potential for emissions from SFs to affect air quality. This hierarchy is illustrated in Figure 4.1.

Figure 4.1: Information used in the assessment of effects on air quality



4.1.3 Elemental composition and fate of elements

The emission rates of most prescribed substances are relatively unaffected by the use of SFs. Although present in traditional and alternative fuels in different amounts, many trace elements tend to be retained in the clinker, while organic compounds are destroyed in the high kiln temperatures.

For organic compounds, the very high temperatures and long residence times in kilns produce a highly efficient environment for destroying the compounds. The highly alkaline conditions decompose chlorinated organic wastes and acid gases and the process retains a large proportion of waste material within the clinker itself.

As a result of a study of dioxin emissions from 16 cement kilns in Germany, Kuhlmann (1996)[18] concluded that dioxin formation is not influenced by the co-firing of SFs, as there was no statistically significant difference in emissions. Dioxins are present at concentrations that are barely detectable and are well below any recommended ELV.

[18] Kuhlmann K., Schneider M. and Sollenbohmer F. PCDD/PCDF emissions from German cement clinker kilns. *Organohalogen Compounds* 27, 78-83, 1996.

Heavy metals are absorbed by the clinker due to its high alkaline content and the scrubbing action within kilns (Guo and Eckert, 1996)[19]:

- refractory metals such as barium, beryllium, chromium and arsenic tend to be incorporated into the clinker at approximately 99.9 per cent;
- about 99.5 per cent of semi-volatile metals such as cadmium, lead and zinc are also trapped in the clinker;
- more volatile metals such as mercury and thallium are largely released into the kiln exhaust gas and are controlled in the specification of the fuel and by the gas clean-up system.

These factors were noted by the Health Protection Agency (HPA) in their statement on the use of SFs in cement kilns[20].

4.1.4 Influence on stack characteristics

Certain emissions, notably NOx, are influenced by process conditions and combustion temperatures rather than fuel composition. However, the use of SF may often entail staged combustion and lower kiln temperatures, resulting in a reduction in NOx emissions. While some SO2 releases from the process are trapped by incoming lime, there may be substantial residual emissions of SO2 from cement kilns, particularly from the older types of process.

The use of SFs results in negligible changes in flue gas volumes or temperatures and hence plume dispersion will not be materially influenced by their use. As discussed later in this section, this is confirmed by several dispersion modelling studies based on SF trial emissions data.

4.1.5 Evaluation of the effects of substitute fuels on ambient air quality

Given the above factors, marked changes in ambient pollutant concentrations are not anticipated other than for SO2 and NOx, possibly. Furthermore, the operator specifies the composition of the SF so as not to unduly affect the cement-making process or compromise the quality of the cement produced, hence limiting the levels of trace elements in the SF.

The following parts of this section present a review of data available for each cement kiln and an interpretation of these data in terms of potential effects of SFs on ambient air quality. The information identified for each plant in terms of emissions data, H1 assessments, ambient monitoring data and dispersion modelling results is summarised in Table 4.2.

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[19] Guo Q. and Eckert J.O. Heavy metal outputs from a cement kiln co-fired with hazardous waste fuels. *Journal of Hazardous Materials* 51, 47-65, 1996.

[20] Health Protection Agency. *Statement on the use of SFs in cement kilns*. 2005. This statement is available from the HPA website.

Table 4.2: Data Identified for the review of effects of SFs on air quality

Plant / Fuel	Tyres	SLF	Profuel®	MBM	RFO	PSP	RDF
Ketton	monitoring, modelling*	monitoring, modelling*	monitoring, modelling	-	-	-	-
Ribblesdale	H1	monitoring, modelling	-	H1, monitoring	-	-	-
Padeswood	monitoring, modelling*	-	monitoring, modelling*	-	-	-	-
Aberthaw	-	-	-	tbc	nyt	-	-
Cookstown	modelling	modelling	-	-	-	-	-
Cauldon	n/a	-	-	-	modelling*	emissions	-
Dunbar	n/a	n/a	-	-	-	-	-
Hope	modelling	-	-	tbc	nyt	-	-
Westbury	monitoring, modelling	-	-	-	-	-	nyt
Barrington	-	n/a	-	-	-	-	-
Rugby	monitoring*, modelling	-	-	-	-	-	-
South Ferriby	-	n/a	-	-	-	-	-

Notes:

-	fuel not used at that site.
*	monitoring not necessarily related to SF use.
n/a	data not available for that SF.
nyt	not yet trialled at that site.
tbc	air quality assessment of trial to be completed.

The data and reports reviewed are summarised below. Sites selected for consideration were based purely on availability of data at the time of preparing the report. All sites would at least have performed an H1 assessment.

For Westbury, Padeswood, Ribblesdale and Rugby (which burn tyres and/or SLF) a more detailed assessment was possible, as both dispersion modelling studies and ambient monitoring surveys were available for these sites. Ketton was included in the review, as dispersion modelling of emissions was carried out for an application for a variation in the use of Profuel®. Cauldon is discussed briefly due to the use of RFO and PSP, although it lacked specific modelling or monitoring data. Hope is included with reference to a comparative dispersion modelling study of conventional fuels and tyres. As can be seen in Table 4.2, there was limited information at the higher end of the method hierarchy for other fuels. Information relating to these fuels is discussed at the end of this section.

Local authority air quality review and assessment reports for the areas were reviewed to determine whether AQMAs were in effect in their districts. Where relevant, these reports state the pollutant for which the AQMA has been declared and the source responsible for causing this pollutant to breach or approach an AQS objective. This information is summarised in Table 4.3.

There are AQMAs declared for NO2 and particulates, but not for SO2. AQMAs declared by Cardiff, West Wiltshire and Rugby are due to traffic emissions rather than industrial sources. The AQMA shown for North Lincolnshire is in the process of being declared, due to high particulate concentrations near the Corus steel works in Scunthorpe. Although none of the AQMAs are designated due to emissions from cement works, the Environment Agency needs to take account of nearby AQMAs when setting emission limit values for regulated processes.

Table 4.3: Local authority Air Quality Management Areas and pollutants

Works	Substitute fuel					Local authority	AQMA	Pollutant (source)
	Tyres	PSP	MBM (AWDF)	SLF	Other			
Aberthaw	-	-	Trials MBM	-	RFO Application	Cardiff County Council	Y	Nitrogen dioxide (roads)
Cauldon	Y	Y	-	RFO application	-	Staffordshire Moorlands District Council	N	-
Hope Kiln 1	Y	-	Trials MBM	RFO application	-	High Peak Borough Council	N	-
Hope Kiln 2	Y	-	Trials MBM	-	-			
Westbury Kiln 1	Y	-	-	Planned trials suspended	-	West Wiltshire District Council	Y	Nitrogen dioxide and particulates PM10 (roads)
Westbury Kiln 2	Y	-	-	Planned trials suspended	-			
Ketton Kiln 7	Y	-	Trials AWDF	Cemfuel®	Profuel®	Rutland County Council	N	-
Ketton Kiln 8	-	-	Trials AWDF	Cemfuel®	Profuel® planned			

Ribblesdale Kiln 7	-	-	Trials AWDF	-	-	Ribble Valley Borough Council	N	-
Padeswood	Trials planned	-	-	Cemfuel® planned	Profuel® planned	Flintshire County Council	N	-
Barrington		-	-	Y	Climafuel® planned	South Cambridgeshire District Council	N	-
Rugby	Trials completed	-	-	-	-	Rugby Borough Council	Y	Nitrogen dioxide (roads)
South Ferriby Kilns 1 & 2	Trial permit lapsed	-	-	Y	Climafuel® planned	North Lincolnshire Council	Y	Particulates PM10 (steel works)

4.1.6 Westbury

Introduction

This section looks at the effects on ambient air quality resulting from changes in emissions due to the use of tyres. The operator made an application to the Environment Agency for the use of tyres as a SF at the Westbury works in August 2001. The operator, in support of this application, submitted an air dispersion modelling study. An authorisation was subsequently issued by the Environment Agency. Tyre burning commenced in November 2001.

The works have been the focus of local concerns regarding air quality for a number of years. The local authority carries out air quality monitoring of traffic-related pollution at Warminster Road, Westbury where PM10, SO2 and NO2 are measured. There is a much lower than average prevalence of winds from the direction of the works at this location, and hence the site is not well suited to provide ambient data relevant to the cement works. The Environment Agency therefore set up additional ambient monitoring at Bratton to address concerns relating to the works. The monitoring site was located approximately 2.5 km to the east of the cement works, where there is a higher than average prevalence of winds from the direction of the works.

Dispersion modelling

In May 2000, Blue Circle Cement (now LCUK) produced a dispersion modelling report on plant operation both with and without tyres, and with one and two kilns in operation. The modelling addressed emissions of SO2 and NOx[21], as it was considered that this would suffice to determine the acceptability of the works. The dispersion models AERMOD and ADMS 3.0 were used.

Changes in pollutant emissions from the use of tyres compared to the coal only baseline are presented in Table 4.4. The most significant changes observed during tyre trials were a marked increase in SO2 emissions and a reduction in NOx emissions. The dispersion modelling study addressed these pollutants.

The stack at Westbury is substantial, with a height of 122 m and an internal diameter of 3.66 m. This relatively high stack will promote dispersion of the discharge and reduce ground level concentrations. The emissions data for the plant are summarised in Table 4.4.

Table 4.4: Emissions data for Westbury works

Parameter	Baseline		Tyre-fuelled operation	
Exit temperature °C	165		180	
Number of kilns	1	2	1	2
Exit velocity, m/s	8.34	16.7	6.6	13.25
NOx emission rate, g/s	83	165	39	78
SO2 emission rate, g/s	2.3	4.6	18	37

[21] A conservative assumption of 50 per cent conversion to NO_2 was made when evaluating the modelled NO_x concentrations.

The above data indicate that the volume flow doubles with both kilns operational, due to the doubling in exit velocity. This will increase plume rise and promote dispersion. NOx emission rates are halved with the use of tyres, whilst SO2 emissions are nearly eight times higher than for the baseline. This is not related to the sulphur content of the tyres, but results from process changes compared with the baseline fuel affecting the oxygen balance, and sulphur retention in the clinker.

These differences in pollutant emission rates are reflected in the long-term and short-term average concentrations reported by the dispersion models, with a halving of NOx concentrations and an approximately ten-fold increase in SO2 concentrations. With tyre burning in both kilns, the increments to the 99.7th percentile of hourly mean SO2 concentrations were reported as 18 µg/m3 and 30 µg/m3 from ADMS 3.0 and AERMOD respectively. These increments from the plant are small compared to the AQS objective of 350 µg/m3.

The dispersion modelling study demonstrates a clear difference in results between the two models, particularly in areas of elevated terrain where this version of ADMS reports much lower maximum hourly results than those derived from AERMOD. However, both models indicated that the maximum concentrations of both pollutants would be significantly less than the AQS objectives, and hence the use of tyres as fuel would not lead to exceedances of these objectives.

Air quality monitoring

The Environment Agency's National Compliance Assessment Service carried out an air quality monitoring survey at Bratton from 31 October 2001 to 20 February 2002 to assess compliance with objectives set out in the 2000 UK AQS for particulates (PM10), SO2, NO2 and CO. Meteorological data was also recorded in order to evaluate the results, quantify the effect of the cement works on local air quality, identify sources causing an appreciable impact and understand the conditions that may give rise to episodes of poor air quality.

The mean particulate concentration during the monitoring period was 20 µg/m3, half of the AQS objective of 40 µg/m3. The 24-hour mean particulate concentrations were typically between 15 and 25 µg/m3, around half of the AQS objective of 50 µg/m3. The 15-minute mean concentrations revealed five events when significant increases were observed. These events were generally of less than an hour in duration; at most they persisted for three hours, and had only moderate or low influence on the 24-hour mean concentrations. None of these events was associated with winds from the direction of the cement works. A similar conclusion was reached from the local authority Westbury site data.

The mean SO2 concentration during the study was 0.9 ppb (2.4 µg/m3), well below the WHO guideline of 50 µg/m3. The 24-hour concentrations were all below four ppb (AQS objective 47 ppb, 125 µg/m3) and one-hour mean concentrations were also less than a tenth of the AQS objective of 132 ppb, (350 µg/m3). The AQS objective for 15-minute means of 100 ppb (266 µg/m3) was met with a similar margin; only five excursions above nine ppb were observed, the highest of which was less than 14 ppb. These minor excursions were associated with a range of wind directions showing that no single source was responsible, with possible influences from distant power stations at Didcot, Aberthaw and Fawley.

The AQS objective for NO2 of 21 ppb (40 µg/m3) was likely to be met at Bratton, as the average during the monitoring period was 8.4 ppb, 40 per cent of the annual objective. The maximum observed one-hour mean was 42 ppb, or 40 per cent of the 105 ppb (200 µg/m3) AQS objective. The highest concentrations were observed during periods of low wind speed when the wind was from the northeast to east and from the south.

The effects of road traffic dominated variations in concentrations during the day during rush hour periods.

The AQS objective for CO is 10 ppm as an eight-hour average. The highest measured value during the monitoring period was 0.82 ppm. The 15-minute average CO concentrations did not exceed 3.5 ppm and these peak concentrations were not found to be associated with a particular wind direction, but occurred at very low wind speeds. Concentrations above one ppm did not coincide with winds from the direction of the Westbury works.

Conclusions

During this period of tyre burning, pollutant concentrations did not exceed or approach any AQS objectives. Results for NO2 and SO2 were comparable to those recorded at six National Environmental Technology Centre (NETCEN) rural monitoring sites. It was concluded that the cement works appeared to have little influence on air quality in Bratton during the monitoring period.

4.1.7 Padeswood

Introduction

Castle Cement made a consolidated PPC application to the Environment Agency for the Padeswood works in 2002. The emissions addressed in the application were from the combined Kiln 1 and 2 stack, the Kiln 3 stack and the new proposed Kiln 4 stack (Kiln 4 has now replaced Kilns 1, 2 and 3).

Reference is made to the dispersion modelling study submitted in support of the application and the summary of the air quality monitoring survey carried out at Pen-y-ffordd by AES.

Dispersion modelling

The dispersion modelling study used AERMOD to assess the operation of Kilns 1, 2 and 3 and a separate assessment was carried out using revised design data (2002) for Kiln 4. Kilns 1 to 3 did not use SFs, although it was proposed to use Cemfuel® in Kiln 4. Revised data for Kiln 4 are summarised in Table 4,5.

Table 4.5: Emissions data for Padeswood Kiln 4

Parameter	
Stack height, m	112.2
Stack diameter, m	3.35
Exit velocity, m/s	12.5
Exit temperature °C	135
Short-term emission rates	
NOx emission rate, g/s	37.5
SO2 emission rate, g/s	37.5
Particles (PM10), g/s	2.25
Long-term emission rates	
NOx emission rate, g/s	37.5
SO2 emission rate, g/s	15
Particles (PM10), g/s	0.75

The dispersion modelling report quotes results for individual years of meteorological data used, as well as mean values for the five years modelled. The mean values reported are discussed below.

Using the above emissions data for proposed Kiln 4, the modelled maximum long-term average increment to NO2 concentrations was 1.3 µg/m3, assuming 100 per cent conversion to NO2, well below the AQS objective of 40 µg/m3. Assuming a 50 per cent conversion to NO2, the maximum modelled 99.78th percentile of hourly mean concentrations was 12 µg/m3, or six per cent of the AQS objective of 200 µg/m3.

The highest modelled increment to annual average SO2 concentrations for the new Kiln 4 was 0.5 µg/m3 at a location to the south east of the plant in Pen-y-fford. This is less than one per cent of the WHO guideline. The highest 99.18th percentile of 24-hourly concentrations was 8.1 µg/m3, approximately six per cent of the 125 µg/m3 AQS objective. The highest 99.73th percentile of one-hour concentrations was 24 µg/m3, or seven per cent of the 350 µg/m3 AQS objective. The model did not give 15-minute results, but on the basis of hourly results the current 15 minute AQS was likely to be met by a large margin.

Modelled particulate concentrations for Kiln 4 included numerous low level fugitive sources, which cause localised effects close to the site. The results were well below annual average and short-term AQS objectives at Pen-y-fford.

Overall, it was clear that the new kiln would bring a considerable improvement.

Air quality monitoring

The Environment Agency Monitoring and Assessment Team reported provisional monitoring results collected by AES at Pen-y-fford during the period June to August 2005. Extrapolating the average results to a year to compare with AQS objectives indicated that PM10 concentrations would be less than 40 per cent and NO2 concentrations less than 10 per cent of respective objectives. The results for PM10, NOx and SO2 concentrations would be less than 80, five and 45 per cent of the respective objectives for vegetation and ecosystems.

4.1.8 Ribblesdale

Introduction

An extensive monitoring survey was carried out by the Environment Agency in 1996. Ribble Valley Borough Council has carried out ambient air quality monitoring at Chatburn and Lillands since then.

Castle Cement made a PPC application to the Environment Agency for the Ribblesdale works in August 2001. In response to the Environment Agency's Schedule 4 notice of December 2001, an expanded air quality assessment[22] was submitted in May 2002 consolidating previous work and addressing the questions raised by the Environment Agency.

The air quality assessment found that existing local concentrations of regulated pollutants were either currently, or projected to be, within AQS objectives for future years. Background concentrations of the key pollutants NO2, SO2 and PM10 in this rural area were less than those in nearby urban areas and well below the AQS objectives.

Tyre trials were carried out on Kiln 7 between May and September 2003 and a report[23] on the findings was accompanied by a request to continue using tyre chips at up to 25 per cent thermal substitution.

Trials of MBM were carried out on Kiln 7 between April and October 2005 and a report[24] on the findings was submitted to the Environment Agency in December 2005. The report was required to be in the format described in the Environment Agency's SFP.

Expanded Air Quality Assessment Report 2002

The releases considered were those from the combined stack for the wet process Kilns 5 and 6 and those discharged from the dry pre-heater pre-calciner Kiln 7 stack. Over 130 sources of particulates were addressed.

The ADMS 3 dispersion model was used with terrain, as the cement plant is located in a valley. Modelling was carried out using a coarse receptor grid spaced at 333-metre intervals. Meteorological data was used from Ringway, Manchester from the Meteorological Office's Numerical Weather Prediction (NWP) model for the years 1998 to 2000.

[22] ERM, (Expanded) Air Quality Assessment: Ribblesdale Works, 2002
[23] Castle Cement Limited, Ribblesdale Works, Report on Tyre Trials May - September 2003, 2004
[24] Castle Cement Limited, Ribblesdale Works, Report on MBM Trials April - October 2005, 2005

Cemfuel® was in use at Ribblesdale, but although the dispersion modelling report found fugitive releases from storage tanks to be insignificant, there was no discussion of whether modelled discharge parameters would differ from those applicable to conventional fuels.

Modelling of long-term and short-term increments to ground level concentrations was carried out using both authorised emission limits and actual emissions for 2000 and 2001. Table 4.6 summarises the stack characteristics, short-term emission rates derived from maximum authorised limits and long-term emission rates derived from the most recent monitoring data (2001).

Table 4.6: Emissions data for Ribblesdale works

Parameter	Kiln 5 and 6	Kiln 7
Stack height, m	109	92
Stack diameter, m	3.6	3.15
Exit velocity, m/s	16.7	21
Exit temperature °C	190	110
Short-term emission rates		
NOx emission rate, g/s	109	74.7
SO2 emission rate, g/s	252	49.8
Particles (PM10), g/s	10.2	12.5
Long-term emission rates		
NOx emission rate, g/s	31.4	41.6
SO2 emission rate, g/s	116	1.9
Particles (PM10), g/s	4.4	1.5

This discussion focuses on the results of most relevance to local ambient air quality monitoring. The following results were obtained from modelling the 2001 long-term emissions and the maximum authorised short-term emissions, using 1999 NWP data as most representative of the three years meteorological data.

Combined stack emissions resulted in a maximum annual mean NO2 concentration of 3.3 µg/m3, less than 10 per cent of the AQS objective, assuming complete oxidation of NO to NO2. The highest 99.78th percentile of hourly mean concentrations (assuming 50 per cent conversion) was 58 µg/m3, less than 30 per cent of the AQS objective.

The modelled maximum annual mean SO2 concentration was 3.9 µg/m3, less than eight per cent of the AQS objective. Using the maximum authorised emission rates, the highest 99.18th percentile of 24-hourly concentrations was 44 µg/m3, approximately 35 per cent of the 125 µg/m3 AQS objective. The highest 99.73th percentile of one-hour concentrations was 113 µg/m3, or a third of the 350 µg/m3 AQS objective. The highest 99.9th percentile of 15-minute results was 138 µg/m3, approximately half of the 266 µg/m3 AQS objective.

The increments to annual and 24-hour average particulate concentrations were found to be less than one per cent and 4.5 per cent of respective objectives.

Apart from a caveat understood to refer to limitations of the ADMS 3 model in addressing the downwash effects of the pre-heater tower, the report concluded that emissions from the kiln stacks were unlikely to breach AQS objectives.

Report on tyre trials

The 2003 Kiln 7 tyre trials were carried out with regard to the Environment Agency's Tyres Protocol and to the SFP. The report (Castle Cement Limited, 2004) on the trials incorporates results from previous studies and addresses the following fuels:

- coal only;
- coal and Cemfuel® (2000 and 2003);
- coal, Cemfuel® and tyre chips;
- coal and tyre chips.

Short-term and long-term dispersion factors were derived from the modelled NOx results in the Consolidated Air Quality Assessment of May 2002. The H1 methodology was used to calculate EQs for each pollutant, including metals. In comparison with long-term EALs, only NOx and CO PCs were found to be not insignificant (PC above one per cent of EAL). In the short-term assessment, only NOx was found to be not insignificant (PC above 10 per cent of EAL). The long-term EQ was dominated by the NO2 contribution for all fuel combinations, as this pollutant contributed between 62 and 72 per cent of the overall fuel combination EQ. However, long-term EQs were below 0.09 for all fuel combinations considered, less than a tenth of the indicative threshold.

It was concluded that the use of tyre chips resulted in no statistically significant change in overall emissions compared with other fuel mixes. Both the 30-minute and daily average emission limits were complied with throughout the trial programme. Dispersion modelling showed that AQS objectives were not exceeded at any time as a result of burning chipped tyres, and this conclusion was supported by the continuous monitoring at Lillands and Chatburn showing no exceedances of AQS objectives.

Report on MBM trials

The 2005 Kiln 7 MBM trial programme focused on the use of a mix of coal, Cemfuel®, tyre chips and MBM, but included baseline testing of coal, Cemfuel® and tyres and additional testing of coal and MBM. The approach again refers to modelling carried out in the Consolidated Air Quality Assessment of May 2002. It used the same dispersion factors and followed the H1 procedure.

The report (Castle Cement Limited, 2005) summarised the MBM trial results. For each fuel mix, the long-term and short-term environmental quotients were calculated. The results are shown in Table 4.7, together with earlier trial results.

Table 4.7: Summary of Ribblesdale Kiln 7 fuel trial results

Fuel mix	EQair long term	EQair short term	EQ NO2 as % of EQair long term
Coal only (Baseline 2000)	0.095	0.131	57.4%
Coal and Cemfuel® (2000)	0.076	0.101	59.1%
Coal and Cemfuel® (Baseline 2003)	0.092	0.144	68.6%
Coal, Cemfuel® and chipped tyres (2003)	0.094	0.149	69.0%
Coal and chipped tyres (2003)	0.091	0.149	71.3%
Coal, Cemfuel® and chipped tyres (Baseline 2005)	0.077	0.125	71.4%
Coal, Cemfuel®, chipped tyres and MBM (2005)	0.097	0.151	64.4%
Coal and MBM (2005)	0.107	0.154	58.8%

The long-term assessment identified emissions of NOx, SO2 and CO as not insignificant (PC above one per cent of EAL). In the short-term assessment, the NOx PC was reported as 12 per cent of the EAL, thus not insignificant (PC above 10 per cent of EAL) in the H1 methodology.

Values of EQair long term for the MBM trials were about a tenth of the indicative threshold. Short-term EQs for the trials were similar to the 2003 results. It was concluded that differences between EQs for any of the fuel mixes in the table were not statistically significant.

The dominance of NOx emissions in the long-term EQ is illustrated in the last column of Table 4.7, where for all fuel mixes NO2 contributes around 70 per cent to EQair. The residual influence of other substances included in the H1 method on these already very low EQs must thus be small.

Using the same dispersion factors, annual average and short-term average ground level concentrations were calculated. The results for all pollutants and fuel types were found to be very low compared with AQS objectives, other than for short-term concentrations of NO2. The short-term NO2 results were around 10 to 12 per cent of the objective for all fuel mixes other than for the 2003 coal and Cemfuel® case, which was slightly lower at eight per cent of the objective.

Air quality monitoring

The Environment Agency carried out a monitoring survey during the period 14 October to 8 December 1996. There had been a number of complaints from members of the public regarding Castle Cement works plume grounding events and odours, and concerns were raised of possible health effects. Throughout this study, eight sites continuously monitored ambient concentrations of SO2 and particulate matter (PM10).

During the period 28 October to 10 November 1996, stack measurements and plume tracking with Lidar were carried out with the use of mobile laboratories. The meteorology during this two-week intensive monitoring period was such that most dispersion conditions were represented and elevated ground level pollutant concentrations were found not to be restricted to any one condition.

The activities at ICI Katalco, Castle Cement and Tarmac were generally representative of normal operations throughout the survey period, although there was a major breakdown of one of the kilns at the cement works. During most of the survey, Cemfuel® was in use.

The Chatburn site (to the north east of Castle Cement) recorded more periods of higher SO2 concentrations than any other site during the study. Although the guideline at this time of 100 ppb (set by the Expert Panel on Air Quality Standards (EPAQS)) was exceeded at this site on two occasions, the air quality met the Committee on the Medical Aspects of Air Pollutants (COMEAP) classification of 'very good' for greater than 99.9 per cent of the time. The AQS objectives for 2005 specified for SO2 an objective of 100 ppb as the 99.9th percentile of fifteen-minute means, measured throughout the year. This allowed for up to 35 exceedances at a site during the year.

For all occurrences of relatively high concentrations at Chatburn, the wind was found to be in a general south west direction. The report does not directly attribute these events to the cement works emissions or to the use of Cemfuel®. It states that "the sulphur mass balances indicate that the majority of the sulphur in the kiln system comes from the quarried raw materials rather than the fuels. Much of this sulphur ends up in the clinker."

At five of the monitoring sites, there were no exceedances of the EPAQS recommendation for PM10, and air quality met the COMEAP classification of 'very good' at these sites. The site recording the greatest number of exceedances was at Clitheroe Hospital, possibly due to vehicular traffic as this site is not predominantly downwind of the industrial sites.

NO2 concentrations were always found to be within the COMEAP 'very good' air quality band and all measurements of trace metals[25] were very low. Although Cemfuel® was a major source of lead in the cement-making process, levels measured in the environment were much lower than the AQS standard.

There were strong indications from a variety of measurements that Castle Cement was the principal source of ground level SO2. The Tarmac site was found to be an additional source of potential significance, given the low height of the stacks. Reports of odour were strongly correlated with elevated concentrations of SO2, but not with the use of Cemfuel®.

It was concluded that air quality in the Clitheroe area was generally very good, and that the number of exceedances of EPAQS recommendations for SO2 and PM10 was not unusually high. Concentrations of these pollutants at most sites were not unusually

[25] The trace metals analysed in this study were: antimony, arsenic, cadmium, cobalt, copper, chromium, lead, manganese, mercury, nickel, thallium, tin and vanadium.

high for a location such as Clitheroe. However, PM10 concentrations at one site, Chatburn, were at the high end of the expected range and were comparable with city centre levels.

The MBM trial report includes a summary of the Ribble Valley Borough Council air quality monitoring results from Chatburn and Lillands. There were no exceedances of AQS objectives for NO2, SO2 or particulate matter (PM10) during the May to September 2005 MBM trials. The highest recorded concentrations were well below these criteria, other than for the highest daily average PM10 concentration which approached the objective. However, these short-term particulate concentrations observed at the monitoring stations may be unrelated to the cement works operation.

4.1.9 Ketton

Introduction

SFs have been used at Ketton since the mid-1990s when Cemfuel® was used on Kiln 7 and Kiln 8. Tyres were introduced to both kilns at a slightly later date. The initial Profuel® trials commenced on both Kiln 7 and Kiln 8 in late 1999 and a trial report[26] on the use of Profuel® in Kiln 7 was prepared in July 2000. A trial report[27] on the use of Profuel® in Kiln 8 was also issued that month. An air quality report[28] addressing background air quality and dispersion modelling of emissions from the plant was prepared in August 2001. Fuel use was not documented in the report.

Best practicable environmental option assessment of Profuel® in Kiln 7

The trial report follows closely recommendations of the Environment Agency's E1 method and IPC Guidance Note S2 3.01, both of which were current at the time. Long-term and short-term EQs were calculated for all substances released for comparison of coal burning and the 40 per cent Profuel®, Cemfuel® and tyres mix. EQs for air based on mean emissions are summarised in Table 4.8.

Table 4.8: Ketton Kiln 7, EQs for coal and Profuel® mix

Parameter	Coal only	Profuel® mix
Long-term EQ	0.0363	0.0204
Short-term EQ	0.175	0.0981

These results are dominated by the contribution of NOx emissions in both fuel scenarios, and the marked reduction in NOx emissions from the Profuel® mix.

[26] AEAT. *BPEO assessment of the burning of Profuel in Kiln 7 at Castle Cement*. 2000a.
[27] AEAT. *BPEO sssessment of the burning of Profuel in Kiln 8 at Castle Cement*. 2000b.
[28] ERM. *Air quality assessment: Ketton Works*. 2001.

The report conclusions based on an analysis of monitoring data, backed up by theoretical argument, were as follows:

- "the burning of Profuel in place of 100 per cent coal is better. Within the realms of statistical analysis, the overall effect of the emissions from Kiln 7 is independent of the choice of fuel;
- all of the fuel mixes from the BPEO assessment have similar environmental effects and they cannot be discriminated from each other within the error of the assessment (one standard deviation);
- for all of the emissions except NOx in the coal only case, all of the substances released are regarded as 'insignificant';
- the introduction of Profuel into the kiln causes no statistically significant change in the emission level of dioxins and furans; for all fuel options, the dioxin and furan emissions are well within the limits set in the authorisation, and the calculated uptakes by human beings are insignificant when compared to the UK average levels;
- only the NOx emissions for the coal only case are slightly above the EQ level 0.02 and considered 'priority for control'. In comparison to the burning of coal only, there is evidence that the introduction of Profuel further reduces these emissions."

Best practicable environmental option assessment of Profuel® in Kiln 8

The trial report uses the same approach as that described for Kiln 7. For the Kiln 8 BPEO study, the use of 100 per cent coal was compared with the use of a Profuel® mix comprising coal, Cemfuel® and Profuel®. The trial authorisation allowed up to 50 per cent thermal substitution with Profuel®.

The EQs for air based on mean emissions are summarised in Table 4.9.

Table 4.9: Ketton Kiln 8, EQs for coal and Profuel® mix

Parameter	Coal only	Profuel® mix
Long-term EQ	0.0629	0.0383
Short-term EQ	0.298	0.147

As was the case for Kiln 7, these results are dominated by the contribution of NOx emissions in these fuel scenarios, and the marked reduction in NOx emissions from the use of the Profuel®.

The conclusions with regard to Kiln 8 are the same as for Kiln 7, other than the following:

- “all of the fuel mixes from the BPEO assessment have similar environmental effects and they cannot be discriminated from each other within the error of the assessment (two standard deviations);
- for all of the emissions except NOx, all of the substances released are regarded as ’insignificant’;
- only the NOx emissions are slightly above the EQ level 0.02 and considered ‘priority for control’. In comparison with coal, there is evidence that the introduction of Profuel further reduces these emissions.”

Air quality report 2001

The air quality report for Ketton reviewed available monitoring data on background air quality. These data showed that pollutant concentrations were below AQS objectives in the area surrounding the works.

Modelling was carried out for the combined discharges from Kiln 7 and Kiln 8 using the input data and emission rates as presented in Table 4.10, although as mentioned above the fuel mix was not stated. Long-term and short-term emission rates (based on authorisation limits) were used to model increments to long-term and short-term ambient concentrations respectively. Kiln 8 is a dry process pre-calciner design of approximately twice the thermal capacity of the dry process pre-heater design Kiln 7.

Table 4.10: Emissions data for Ketton works

Parameter	Kiln 7	Kiln 8
Stack height, m	92.7	92.7
Stack diameter, m	2.5	3.0
Exit velocity, m/s	16.8	25
Exit temperature °C	115	120
Short-term emission rates		
NOx emission rate, g/s	57	151
SO2 emission rate, g/s	30	61
Particles (PM10), g/s	2.5	5.0
Long-term emission rates		
NOx emission rate, g/s	19	59
SO2 emission rate, g/s	0.28	3.4
Particles (PM10), g/s	1.5	2.8

The highest modelled annual average NO_2 concentration for the operation of the two kilns was 2.55 µg/m3 (assuming 100 per cent conversion of NOx), or six per cent of the AQS objective. The highest 99.79th percentile NO_2 concentration was 28.3 µg/m3 (assuming 50 per cent conversion of NOx), or 14 per cent of the AQS objective and hence not significant. Modelled concentrations of SO_2 were not significant, as the annual mean was 0.11 µg/m3 and the 24-hour and hourly percentile results were 0.90 and 2.4 µg/m3 respectively. The modelled concentrations of PM10 were not significant, as the annual mean was 0.15 µg/m3 and the hourly percentile result was 0.56 µg/m3.

It was concluded that emissions from the Ketton works had a small impact on local air quality and that ground level concentrations resulting from these emissions would not lead to breaches of AQS objectives. Various atmospheric modelling inputs were considered in more detail, including the pre-calciner tower and a smaller receptor grid. Inclusion of a tall narrow building gave rise to markedly elevated predicted short-term concentrations, but these results likely overstated this effect, due to the use of the ADMS model for this study.

Profuel® dispersion modelling

A two-page untitled document was provided by Castle Cement which briefly described a generic modelling study using AERMOD for a baseline case and Profuel® case. The emission rate was fixed for both scenarios, the only difference being a 1.8°C increase in temperature and a small reduction in efflux velocity with the Profuel® case. Modelled ground level concentrations were in most cases identical, demonstrating that extremely small differences in plume characteristics would not affect the plume dispersion. Any differences in the pollutant emission rates found in practice between the baseline and Profuel® case would be proportionately reflected in ground level concentrations.

4.1.10 Cauldon

Application to use processed sewage pellets

Lafarge Cement UK submitted an application for permanent permission to use PSP at Cauldon in September 2003, following a seven-month trial period. The previous disposal route at sea was no longer available, thus increasing the amounts to be disposed of in landfill or as fertiliser in agriculture. The trial used up to 17% of the heat input from PSP, the remainder being from coal, other than during the final stage of the trial when a 15% petroleum coke, 85% coal mix was used with PSP. The plant was already permitted to use tyre chips at up to 60% thermal substitution. However, on a mass basis the contribution from tyres was less than 2.5% of the fuel used during the baseline and PSP trials. The trials entailed PSP substitution rates of up to approximately 2.5% on a mass basis, equivalent to some 17% of the heat input to the kiln system.

No significant difference in NOx emissions was found for PSP compared with the baseline case. There was a marginal increase in CO emissions (seven per cent) and a similar increase in SO_2 emissions, but the latter was more closely related to the sulphur content of raw materials than the type of fuel used. Measurements of VOCs, HCl, HF, metals and dioxins showed no variation due to PSP use.

Application to use recovered fuel oil

Lafarge Cement UK made an application to use RFO at the Cauldon works in August 2005, subject to a successful operational trial. This fuel is similar to diesel light up fuel used in the cement industry. RFO is a non-hazardous material in terms of the WID. RFO composition meets specified limits for sulphur, chlorine, metals and polychlorinated biphenyl (PCB) content.

Dispersion modelling of the Cauldon works emissions was carried out in 2003. Lafarge Cement state that these results were used as the basis for the RFO application, as there was no change in emissions or dispersion characteristics of the discharge as a result of using RFO.

4.1.11 Hope

Application to use tyre chips

Lafarge Cement UK presented a dispersion modelling study of emissions from the Hope works in July 2002 alongside an application[29] to burn tyre chips. The report used emissions data from tyre burning trials and from conventional fuel firing (coal and petroleum coke) for a comparative dispersion modelling study. The input data are summarised in Table 4.11.

Table 4.11: Emissions data for Hope works

Parameter	Normal firing	Firing with tyres
Stack height, m	132	132
Stack diameter, m	4.52	4.52
Exit velocity, m/s	10.8	13.4
Exit temperature °C	205	199
Emission rates		
NOx emission rate, g/s	172	139
SO2 emission rate, g/s	49.7	97.7
Particles (PM10), g/s	0.185	0.149

The increase in SO2 emissions with tyres resulted in short-term percentile levels of 10.9 μg/m^3, 32 μg/m^3 and 42 μg/m^3 for the 24-hour, one-hour and 15-minute averaging periods respectively. These concentrations corresponded to 8.7, 9.1 and 15.7 per cent of respective AQS objectives. Use of tyres reduced the hourly percentile NO2 concentrations to 12 per cent of the AQS objective.

[29] Lafarge Cement UK. *Assessment report on trials and demonstration of compliance with Authorisation No. AI 0608 Variation BK5266 in order to allow permanent use of chipped tyres as a fuel at Lafarge Cement UK, Hope Works, Derbyshire*. 2002.

The dispersion modelling report conclusions were summarised as follows:

- "the atmospheric dispersion modelling predicts that the incremental effect on ground level concentrations of the significant pollutants from the Cement works at Hope under normal operation, both with and without tyres, are unlikely to cause a breach of the relevant AQS objectives for 2003-2005;

- maximum impacts resulting from emissions of SO2 are well within the standards and guidelines under normal operation. The use of tyres as a supplementary fuel increases the SO2 ground level concentrations expressed as the 99.2nd percentile of the 24-hour mean, the 99.7th percentile of the one-hour mean and the 99.9th percentile of the 15-minute mean, by approximately 70 per cent. However, this change is small compared to the AQS objectives;

- maximum impacts resulting from emissions of NOx are well within the standards and guidelines, both with and without tyres. Use of tyres reduces the impact of the works by around 30 per cent for all cases and all statistics, reflecting the reduced emissions of NOx when tyres are used as a supplementary fuel. This change is small compared to the AQS objectives;

- maximum impacts due to emissions of CO and particles are very small in relation to standards and objectives, both with and without tyres."

4.1.12 Rugby

Introduction

This section considers the effects on ambient air quality of predicted changes in emissions from the use of tyres at the Cemex UK Rugby works.

This plant is located 1.5 km from the centre of the town of Rugby, and is situated close to the residential areas of New Bilton, Long Lawford and Newbold on Avon. It has been the subject of significant public scrutiny over the past few years as a result of concerns over emissions to air.

In August 2001, Rugby Cement Ltd submitted an application for a PPC permit (to replace the IPC Authorisation). The application included a proposal to use tyres as a partial substitution for the existing fuels, coal and petroleum coke. Following substantial consultation with the public, public health bodies, local authorities and other statutory consultees, the permit was granted[30].

In order to make a comparison between burning coal alone and burning coal with tyres, baseline emissions monitoring was carried out at the works. The monitoring showed emissions to be in compliance with the permit.

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[30] Environment Agency. *Non-technical summary of the Environment Agency's decision on the application from Rugby Limited for a permit under the Pollution Prevention and Control Regulations 2000 in respect of Rugby Cement Works*. 2003.

In May 2004, the trial involving burning tyres as a part fuel in the cement-making process began. However, the trial was halted on 1 July 2004 following an incident at the plant unrelated to the use of tyres as fuel. Formal trials re-started on 21 October 2005 and lasted until 26 December 2005. The report on the trial was received by the Environment Agency on 24 October 2006, and this was subject to a three-month public consultation exercise. The Environment Agency announced that it would allow Cemex to use tyres on 5 February 2007.

Dispersion modelling

As part of the assessment of the Rugby Cement PPC application in 2002, the Environment Agency's Air Quality Modelling and Assessment Unit (AQMAU) carried out an independent modelling study to assess the air quality impacts of proposed emissions from the use of conventional fuels[31]. The report assessed the impacts of SO2, NOx and PM10 emissions from the main stack. Emissions of PM10 from auxiliary sources were also considered.

Modelling was carried out using both ADMS 3.1 and AERMOD PRIME, based on the emission limits contained in the PPC permit. Meteorological data from Elmdon was used in the study. Downwash effects of the pre-heater tower on the main stack emissions were included in the model. The emissions data used in the AQMAU study (Environment Agency AQMAU, 2003) is summarised in Table 4.12.

Table 4.12: AQMAU emissions data for Rugby works

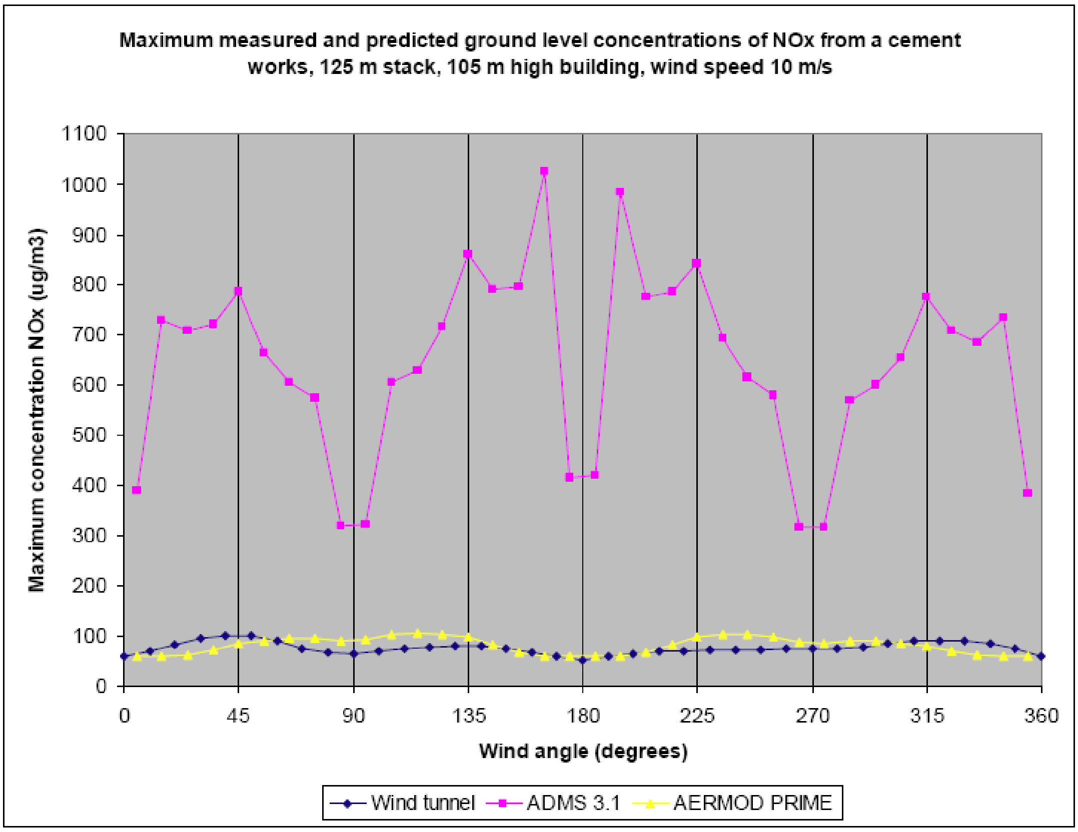
Parameter	Main stack
Location of stack	448761, 275739
Stack height (m)	115
Stack diameter (m)	4.2
Exit temperature (K)	423
Exit velocity (m/s)	17
Emission rate (g/s)	39 (SO2) 131 (NOx) 8 (PM10)

To assess uncertainties in the performance of dispersion models ADMS 3.1 and AERMOD PRIME, wind tunnel data[32] for a similar cement works were used in a comparison study, the findings of which are shown in Figure 4.2. The AERMOD PRIME results are very similar to measurements made in the wind tunnel and the model performance is not unduly sensitive to wind direction in relation to building geometry. ADMS 3.1 was found to seriously overestimate short-term maximum ground level concentrations and to be very sensitive to wind direction. At wind directions of zero and multiples of 90 degrees, the ADMS results are approximately five times too high. For certain wind angles, the ADMS results are over fifteen times too high. Therefore, the assessment of impacts was based on AERMOD PRIME results.

[31] Environment Agency Air Quality Modelling and Assessment Unit. *Air quality modelling and assessment of air quality impact of emissions from Rugby Cement*. 2003.
[32] Harvey, D. J. and Obasaju, E. D. Accuracy of techniques for modelling the effects of building downwash on the dispersion of emissions to atmosphere. *Clean Air* 29 (2), 42-44, 1999.

The results showed that, within model uncertainty, air quality objectives for SO2 and NO2 were unlikely to be exceeded. However, due to the high background concentrations of PM10, air quality objectives for PM10 were likely to be exceeded.

Figure4.2: Graph comparing modelling results with wind tunnel data



Rugby Borough Council (RBC) also carried out dispersion modelling as part of their review and assessment of air quality. The AAQuIRE model was used to estimate concentrations of NO2 and PM10 arising from road traffic and Cemex site emissions. Details of the main stack emissions characteristics (RBC, 2005) are given in Table 4.13 below. These parameters vary slightly from those used by AQMAU; in particular, the exit temperature is around 30 degrees higher while emission rates are lower as they were derived from measurements (November 2004 and January 2005) rather than limit values.

Modelling was carried out using meteorological data from Coleshill and assumed continuous operation for 365 days of the year. Emissions of NOx from the main stack and PM10 from eighteen low level particulate point sources and the main stack were included in the model.

Table 4.13: RBC emissions data for Rugby works

Parameter	Main stack
Location	448762, 275743
Stack height (m)	115
Stack diameter (m)	4.2
Exit temperature (K)	454
Exit velocity (m/s)	19.9
Emission rate (g/s)	4.6 (PM10) 58.9 (NOX)

Emissions from the Cemex site were responsible for increased ground level concentrations in the vicinity of the site. Modelled concentrations at all (67) receptors were below the annual mean objectives for all pollutants and years, except for NO2 at the Webb Ellis Pub (41.2 µg/m^3). Monitoring results were in good agreement with the model, although the model was shown to overestimate slightly.

The contribution by the Rugby works to measured NOx concentrations was less than two per cent at all monitoring sites. For PM10, background sources were found to be the greatest contributor to concentrations while at Parkfield Road and Lawford Road, the plant was the second most significant contributor (six and nine per cent respectively). The plant was more significant with regard to PM10 than NOx due to the large number of low level PM10 sources at the site, while NOx was only emitted in significant quantities from the main stack.

Air quality monitoring

The Environment Agency and RBC carried out ambient air quality monitoring at Parkfield Road, a location considered to be close to the maximum ground level concentration. Monitoring showed little measurable impact from the cement kiln stack. The main air quality impacts were found to be traffic pollution and other sources to the east of the monitoring site. No AQS objectives were exceeded. Some patterns of dust from other sources at the works were detected and improvements were requested by the Environment Agency to address these, although this was not connected to the use of SFs.

RBC recently completed their review and assessment[33] of air quality. The final stage of the assessment focused on the Rugby Cement works, which showed that AQS objectives were not breached at any continuous monitoring site, for either NO2 or PM10 between 2003 and 2005. The highest concentrations were measured at the Newbold Road roadside site, while the lowest concentrations were measured at Webb Ellis Road, Long Lawford and Parkfield Road. Concentrations in 2003 were higher than those measured in 2004 and 2005 (January to September). The PM10 daily mean objective was easily met in all years, including in 2004 when the limited tyre trials took place.

[33] Rugby Borough Council, Air Quality Further Assessment, 2005. This report is available from the Rugby Borough Council website.

Conclusions

Limited monitoring data are available for the tyre trial period at Rugby works, due to the early halting of operations. However, RBC recently concluded that AQS objectives were not breached at any continuous monitoring site in Rugby for either NO2 or PM10 between 2003 and 2005. Concentrations were approximately half the objective level at Parkfield Road (situated at the estimated point of maximum ground level concentration of the works). The tyre trial has recently been completed, but Cemex has not yet submitted the results.

Modelling carried out by both the Environment Agency and RBC concluded that the air quality objectives for SO2 and NO2 were unlikely to be exceeded. Environment Agency modelling found that PM10 objectives might be exceeded due to high background levels, while RBC modelling suggested the maximum contribution from the works to modelled concentrations of PM10 was less than 10 per cent at any monitoring site. It is therefore unlikely that the use of SFs at the works would in itself cause AQS objectives to be breached.

Conclusions on the effects on air quality of substitute fuels

All available ambient air quality data for works using SFs were evaluated. The data did not show any effect on measured concentrations that could be unequivocally attributed to a change in emissions from a cement works, due to the use of the substitute fuel.

There was little evidence of an influence of cement works emissions on ambient air quality monitoring data, irrespective of the fuel used.

The most intensive monitoring survey carried out in the vicinity of cement works was the Environment Agency's study in the Ribblesdale area during Cemfuel® use in 1996. Although the works was thought to be the principal source of ground level SO2, air quality in the area was considered to be generally very good, with a not unusual number of short-term exceedances of air quality criteria at that time. It was concluded that such events would not lead to a breach of the percentile-based AQS objective, as this allows for a small number of exceedances in a year. These events were not attributed to the use of Cemfuel®. Monitoring sites near cement works generally demonstrated compliance with AQS objectives. Pollutant concentrations in the vicinity of works in rural areas were typically a small fraction of AQS objectives.

Relatively high particulate (PM10) concentrations at certain monitoring sites were due to influences other than the stack discharge, such as local traffic or numerous low level sources of particulates typically found at cement works. However, particulate releases were not found to be related to the use of SFs.

In 1996, the Environment Agency's Ribblesdale monitoring exercise concluded that air quality in the Clitheroe area was generally very good and that the number of exceedances of EPAQS recommendations for SO2 and PM10 was not unusually high. A 2002 air quality assessment reported background levels of SO2, NO2 and PM10 as being well below AQS objectives.

During the MBM trial at Ribblesdale, the highest daily average PM10 concentrations approached the objective, but these results may have been unrelated to the cement works operation.

At Westbury, monitored long-term and 24-hour average particulate (PM10) concentrations were approximately half of the respective AQS objectives. Short-term (15-minute) excursions in PM10 concentrations were observed during brief periods, resulting in only moderate or low influence on 24-hour average concentrations, but such events were found not to be associated with winds from the direction of the cement works.

At Padeswood, monitoring demonstrated that PM10 concentrations would be less than 40 per cent and NO2 concentrations less than 10 per cent of the respective AQS objectives.

Dispersion modelling studies also tended to confirm that increments to long-term and short-term pollutant concentrations were small fractions of the AQS objectives, irrespective of whether conventional fuels or SFs were used.

At Westbury, modelled short-term and long-term ground level concentrations of SO2 were significantly less than AQS objectives, and it was concluded that the use of tyres would not lead to exceedances of the objectives.

At Padeswood, the long-term and short-term increments to NO2, SO2 and particulate concentrations were all well below (less than 10 per cent) of the respective AQS objectives.

At Ribblesdale, increments to long-term concentrations of NO2, SO2 and particulate concentrations were less than 10 per cent of the respective AQS objectives. Modelling the maximum authorised emission rates gave increments to the short-term percentile concentrations of NO2 of less than 30 per cent. For SO2, the 24-hourly and hourly average concentrations were 35 and 32 per cent of the respective AQS objectives.

At Ketton, modelling of short-term SO2 emissions showed that the short-term and long-term ground level concentrations were insignificant.

Where comparative assessments were carried out using the Environment Agency's H1 methodology, EQair for individual pollutants and overall EQ values were all a small fraction of one, irrespective of the fuel mix used. These results were invariably dominated by changes in NOx emissions, as the EQair for NO2 alone could be over 70 per cent of the EQair long term.

For Ketton Kiln 7 and Kiln 8, it was reported that the base case and SF mix considered as part of the BPEO study could not be discriminated from each other in terms of EQair within the error of the assessment. All substances released were deemed to be insignificant in terms of EQair, other than for NOx for both the coal and SF mixes in certain cases.

The Ribblesdale Kiln 7 MBM trials report summarised EQ values from previous studies for a number of base cases and fuel mixes. It was concluded that the differences between EQs for any of the fuels were not statistically significant. In the short-term assessment all pollutants were deemed to be insignificant, and the long-term assessment identified only NOx, SO2 and CO as not insignificant (but all less than seven per cent EAL) in certain cases.

In most cases, changes in stack emissions were found to be small compared to the relevant ELVs. The elemental composition of fuels was not necessarily linked to changes in pollutant emissions, due to the varying fate of specific elements in the cement process. One of the most significant changes in emissions due to SF use was the increase in SO2 emissions at Westbury when using tyres, and this was attributed to air ingress affecting the process rather than any marked difference in the sulphur content of fuels. However, aside from such exceptional process-related effects, it could be concluded that other SFs with similar elemental compositions would not markedly change ground level concentrations compared to the relatively minor variations discussed above.

There are no AQMAs in the UK designated as a result of cement works.

The HPA have stated that, if well managed and maintained, cement kilns are “efficient and effective processes for burning substitute fuels” and that any changes in emissions are “modest and site specific” and therefore will have little effect on ambient air concentrations.

4.2 Health Risk Assessment

The use of SFs in cement kilns has been the source of considerable public concern due to the perceived health risk of emissions generated by burning such fuels in cement kilns. This section reviews health risk assessments (HRAs) undertaken following trials or normal use of SFs. Operators, agencies and public health bodies produced these reports.

HRA is a standard technique for evaluating the toxic properties of substances, assessing human exposure to substances to ascertain the likelihood that the exposure will lead to adverse health effects, and characterising the nature of the effects. Health risk is defined as the probability of injury, disease or death from exposure to the substance. This probability may be expressed in quantitative terms, taking values from zero to one, or in qualitative terms, such as high, low or trivial.

There are two main methods of undertaking health risk assessment:

- Consideration of the impacts on human health through the direct inhalation of ‘classic’ air pollutants: NOx, SO2 and particulate matter (PM10). This is assessed using the methodology set by COMEAP[34], which uses the results of epidemiological studies to derive exposure-response coefficients expressed as a percentage increase in a baseline health rate in the population per unit increase in pollutant concentration. The outputs are the number of deaths brought forward (due to emissions of SO2 and PM10) and number of additional hospital admissions (due to exposure to all pollutants).

- A health risk assessment based on the maximum ground level pollutant concentrations, following the United States Environmental Protection Agency (US EPA)[35] or Her Majesty’s Inspectorate of Pollution (HMIP)[36] human health risk assessment methodologies; these assessments produce estimates of exposure via the food chain pathway to heavy metals and dioxins. Intakes are compared with reference doses set by US EPA and tolerable daily intakes (TDIs) recommended by WHO. In addition, the incremental cancer risk is estimated by combining intakes via ingestion and inhalation with cancer slope factors. This risk due to cement plant emissions can be compared with the acceptable annual incremental risk set by the Royal Commission on Environmental Pollution (RCEP)[37] of one in a million.

[34] COMEAP. *Quantification of the effects of air pollution on health in the United Kingdom*. London, the Stationery Office, 1998.
[35] US EPA. *Human health risk assessment protocol for hazardous waste combustion facilities*. 1998.
[36] HMIP. *Risk assessment of dioxin releases from municipal waste incineration processes*. 1996.
[37] RCEP. *Waste incineration and the environment*. Seventeenth Report of the Royal Commission on Environmental Pollution, HMSO, London, 1993.

When applying the risk assessment methodology, it is common practice to assess the health risk of a hypothetical maximum exposed individual (HMEI). Several assumptions are made when deriving modelling parameters to ensure the assessment will overestimate the levels of substances in foods, and so generate a conservative estimate of health risk. For instance:

- the plant is assumed to operate continually at permitted emission limit values. In practice, this is unlikely to be the case and actual emissions would be lower than those for which the assessment was conducted;

- the HMEI lives in the area of maximum impact and consumes all of his/her animal, dairy, vegetable and cereal products from this area;

- of the metals considered, there is good evidence that arsenic is not genotoxic and, therefore, the calculation of carcinogenic risk via inhalation greatly overestimates the risk.

A review of all available information was carried out for each SF considered in this report. The information reviewed included emissions data, air quality modelling results, HRA and health impact assessment (HIA) reports, and epidemiological studies. This information is summarised in Table 4.14 below. HRA and HIA reports and epidemiological studies contained more detailed information on health risk compared to emissions data and air quality modelling results. The table below clearly illustrates the variety of information available; for instance, there are many more reports for tyres and SLF than for PSP or RDF. To some extent, this reflects the length of time that the SFs have been considered as viable fuels.

As with many other industrial processes, only a few studies have considered effects on the general public from exposure to emissions from cement kilns, whether burning conventional fuels or SFs. A comparison of ground level concentrations with air quality standards was made earlier in this section, but is included here where no HRAs have been undertaken for some new fuel types.

This section of the report is structured such that each SF is discussed separately, and for each SF, information on heath risk from the relevant cement plant is presented. Conclusions from individual reports are presented under each cement plant heading, and a final set of overall conclusions is provided at the end of this section.

Table 4.14: Data identified for the review of health risks from SFs

Plant/Fuel	Tyres*	SLF**	Profuel®	MBM	RFO	PSP	RDF
Ketton	n/a	soil sampling	HRA	-	-	-	-
Ribblesdale	emissions	epidem.	-	emissions HMIP^	-	-	-
Padeswood	HMIP, COMEAP^	-	HMIP, COMEAP^	-	-	-	-
Aberthaw	-	-	-	tbc	nyt	-	-
Cookstown	modelling	modelling	-	-	-	-	-
Cauldon	monitoring	-	-	-	nyt	emissions	-
Dunbar	COMEAP	COMEAP	-	-	-	-	-
Hope	HMIP, COMEAP	-	-	tbc	nyt	-	-
Westbury	HMIP	-	-	-	-	-	nyt
Barrington	-	n/a	-	-	-	-	-
Rugby	HIA	-	-	-	-	-	-
South Ferriby	-	n/a	-	-	-	-	-

Notes:

- \- fuel not used at that site.
- * review of four plants (AEAT, 2003).
- ** review of use of SLF in UK (Environment Agency, 2003).
- ^ HRA not specifically for the SF in question.
- tbc in progress, to be provided by operator.
- nyt not yet trialled.
- n/a data not available for that SF.
- epidem epidemiological study.

Tyres

A report produced by AEA Technology[38] looked at tyre burning at four cement kilns in the UK: Cauldon, Ketton, Westbury and Hope. On the basis of the limited available evidence, it found:

- NOx emissions reduced at all four sites;
- SO2 emissions increased at two sites;
- CO emissions increased at two sites;
- particulate emissions increased;
- VOC emissions decreased;
- zinc emissions increased.

There was no conclusive evidence for an increase or decrease in dioxin or metal emissions. Hence, no conclusion can be drawn about the potential health risk of these emissions.

4.2.1 Ribblesdale

A general HRA was undertaken for emissions from Kilns 5, 6 and 7 as part of the air quality assessment of the Ribblesdale works (ERM, 2002). The assessment used HMIP methodology to assess exposure to dioxins and metals for an HMEI via inhalation and ingestion of food. The additional lifetime carcinogenic risk from inhalation of metals (arsenic, cadmium, chromium and nickel) plus ingestion of arsenic (US EPA method only) was assessed using US EPA cancer risk factors and WHO guidelines. The study also addressed non-carcinogenic effects from ingestion of metals in terms of a hazard index (HI). A value of less than one indicates that emissions would not cause an adverse health risk; in both cases, the HI was three orders of magnitude below this criterion. The HMEI intake of dioxins was calculated and compared to the WHO[39] TDI. The results are summarised in Table 4.15 below.

Table 4.15: Health risk assessment results for Ribblesdale

Health effect	Kilns 5, 6 and 7	Kiln 7 only	Criteria
Criskinh (lifetime)	1.7 x 10-8	1.2 x 10-8	7 x 10-5 (1 in 14,300)
Crisking (lifetime)	3.2 x 10-9	3.1 x 10-9	
HIing	0.0042	0.0021	1.0
Dioxin (pg/kg/day)	0.05	0.005	1.0

[38] AEA Technology. *Review of tyre burning in cement kilns*. Environment Agency, 2003.
[39] WHO. *Dioxins and their effects on human health*. Fact sheet available from WHO website.

The tyre trial report for the Ribblesdale works (Castle Cement Limited, 2004) reported that using chipped tyres as an alternative fuel at 25 per cent thermal replacement on Kiln 7 led to no statistically significant change in overall emissions compared to other fuel mixes (coal only, coal and Cemfuel®). Uptake of dioxins through the food chain was assessed in the PPC application based on Kiln 7 emissions data for burning coal. Since dioxin emissions from chipped tyres were even lower than for the base case, it was not considered necessary to recalculate TDI figures for the tyre trial.

4.2.2 Padeswood

A HRA specific to tyre burning at Padeswood was not identified. However, as part of the application to burn SFs, Castle Cement submitted a HIA which compared emissions from the existing Kilns 1, 2 and 3 with that of the (then) proposed Kiln 4. Both assessments applied the HMIP methodology to address health risks associated with exposure to heavy metals and dioxins, while the COMEAP method was used to assess health effects from emissions of NOx, SO2 and PM10. The results for all assessments are summarised in Table 4.16 (results for carcinogenic risk were obtained using US EPA cancer risk factors).

Table 4.16: Health risk assessment results for Padeswood

Health effect	Kilns 1, 2 and 3	Kiln 4 only	Criteria
Criskinh (lifetime)	3.0 x 10-8	2.9 x 10-7	7 x 10-5 (1 in 14,300)
Crisking (lifetime)	9.3 x 10-9	2.4 x 10-7	
HIing	0.0142	0.020	1.0
Dioxin (pg/kg/day)	< 0.33	< 0.013	1.0
Deaths brought forward	2.67	0.38	5,500 (background)
Additional respiratory hospital admissions	3.93	0.75	6,500 (background)

The assessment carried out for Kilns 1, 2 and 3, which are no longer in use, determined that health risks were an order of magnitude higher than those for Kiln 4, although both were found to be insignificant in terms of human health. The increase or reduction in pollutant emissions as a result of burning SFs would not be expected to cause significant changes in health risk such that any of the above criteria would be exceeded. COMEAP results were considered to be very low and unlikely to alter significantly if emissions from the cement works were to change with the use of SFs.

The Environment Agency conducted an independent HRA using the HMIP (1996) and US EPA (1998) methodologies. Exposure of both HMEI adults and children were considered in this case. The results of the Environment Agency's HRA were consistent with the results of the applicant. The maximum total lifetime risk of carcinogenic effects due to emissions from Kiln 4 was found to be of the order of one in 1.8 million for an adult HMEI. The maximum predicted intake of dioxins and furans (0.05 pg TEQ/kg/day) was significantly less than the WHO TDI. Predicted intakes of metals due to emissions from Kiln 4 were also significantly less than US EPA reference doses for all metals for which limits were set in the WID.

As a result of widespread public concern regarding the health impact of Kiln 4 burning SFs, the Environment Agency commissioned a further independent assessment. This used the COMEAP methodology to assess the health impact of releases from Kiln 4 of SO_2, NO_2 and PM_{10}. The impact on public health was found to be very small, while uptake of dioxins and furans was found to be less than 1.3 per cent of the TDI specified by WHO.

The Flintshire Local Health Board carried out an assessment of the data provided by the applicant and by the Environment Agency and concluded that "the health impact of kiln 4 is extremely small and the impact well below any level that would be visible in local health statistics or detected by any special local health studies...The overall impact of emissions from the proposed kiln 4 on the health of local residents is significantly less than the current impact of emissions from existing operations on the site. This will result from improvements in local air quality following the commissioning of the new kiln to replace operations in the old kilns. The evidence suggests that residents... are very unlikely to suffer any harmful effects from authorised emissions of any pollutant from the proposed kiln and, compared with current emissions from the site, the chances of any harmful health effects will be reduced."

4.2.3 Cauldon

The report on trials using chipped tyres (September 2001) presents the results of CEM and extractive stack measurements. Extractive measurements showed a 13 per cent reduction in NO_x emissions compared with baseline when chipped tyres were burnt in the kiln. A comparison of CEM data for NO_x during the trial periods and baseline emissions showed little apparent change; however, comparing with post-trial operation, a similar reduction to the extractive test results was indicated.

An increase in the emission of CO was indicated; however, over half of this increase was considered to be due to process changes unrelated to tyre addition rates. Emissions of SO_2 and particulates (total particulate matter (TPM)) were shown to be independent of tyre feed rate. There was no appreciable difference between extractive measurements of VOCs, selected organics (butadiene, chloromethane), HCl, dioxins and furans, PAHs and trace metals during chipped tyre burning compared with the baseline.

These results indicate that the impact on human health remains unchanged by the use of chipped tyres.

4.2.4 Cookstown

A HRA was not identified for the use of tyres at Cookstown. However, air dispersion modelling results showed that the incremental effect on ground level concentrations of significant pollutants (SO_2, PM_{10}, NO_x and CO) would be unlikely by themselves, or in combination with background concentrations, to cause a breach of AQS objectives.

Modelling results showed that tyre burning would decrease NO_x concentrations by 17 per cent. SO_2 concentrations were shown to increase by a factor of two; however, this was considered to be due to changes in the composition of raw materials during the trial. Increments to ground level concentrations of CO and PM_{10} were negligible and well below AQS objectives.

4.2.5 Dunbar

A study was carried out to compare two fuelling options (with and without tyres) and two operational scenarios (raw mill on and off) at the Dunbar works. The comparison focused mainly on atmospheric releases of NOx, SO2 and PM10. The study suggested that the combustion of tyres with traditional fuel (coal and pet coke) was a better option than combustion of traditional fuel only under both operational scenarios, due to lower emissions of the three pollutants. The study did not consider emissions of other pollutants such as zinc, PCBs, dioxins and furans and VOCs, due to the absence of relevant EALs.

A HRA was carried out for tyre burning for the pollutants described above, using the COMEAP methodology. It was estimated that the annual number of deaths brought forward by emissions from the works would be around 0.051 for the base case and 0.041 for the tyre burning case. The number of additional respiratory hospital admissions would be around 0.073 and 0.059 for the base case and tyre burning case respectively. The number of deaths brought forward was dominated by SO2 emissions. Based on the emissions data, tyre burning was found to result in a reduction in deaths brought forward and hospital admissions compared to the base case (without tyres). However, in both cases the numbers were negligible compared to other effects such as extremes of ambient temperature.

4.2.6 Hope

A HRA comprising COMEAP and HMIP studies was produced for Hope works as part of the assessment report on trials and demonstration of compliance with authorisation, to allow permanent use of chipped tyres at the Hope works.

The HMIP assessment used modelled maximum annual mean concentrations to predict uptake of trace metals and dioxins, with and without the use of tyres, for the HMEI. Despite extremely conservative exposure assumptions, the predicted incremental intake of dioxins was negligible compared to the WHO TDI and typical background rates, both with and without tyre burning. Dioxin intake was 60 per cent lower for the ‘with tyres’ case, although this was not considered to be a significant decrease due to the very low levels involved.

Although non-carcinogenic effects of trace metals from tyre burning were calculated to be twice those for the base case, both results were extremely low, at four orders of magnitude below the criterion of one for total metals. This difference was primarily due to the increase in emissions and hence ground level concentrations of mercury. The lifetime carcinogenic risks from exposure to trace metals were in both cases four orders of magnitude below the RCEP assessment criterion of one in 14,300, with a marginal and insignificant increase in risk during tyre burning.

Emissions of dioxins and trace metals from the works for the existing case or when burning tyres are not predicted to result in an unacceptable risk to health.

The COMEAP study was performed using the outputs of dispersion modelling and population and health statistics for the local area. The annual number of deaths brought forward by emissions from the works was estimated to be approximately 0.4 for the base case and 0.6 when burning tyres, while the number of respiratory hospital admissions was calculated as approximately 1.7 for the base case and 1.6 for tyres. The number of deaths brought forward was dominated by the effects of SO2 emissions, which showed a doubling during tyre burning. Predictions of the number of hospital admissions included emissions of NO2, which showed a 20 per cent decrease when burning tyres. However, results for both cases were considered to be insignificant when compared with background rates. In practice, it would not be possible to identify the small effect of the works within local health area statistics.

4.2.7 Westbury

Possible impacts on human health from emissions of dioxins and trace metals from the Westbury works were assessed as part of an application to substitute tyres at 24 per cent. The operator used standard HRA methodology based on the source-pathway-receptor approach. The risk when burning coal/pet coke only was compared with that resulting from the fuel substitution.

The risk assessment method was based on conservative exposure scenarios for the HMEI. In addition, the cancer potency factors used included those for substances classed as B2 carcinogens. This classification implies that there is an inadequate amount of evidence as to their carcinogenicity in humans.

The assessment showed that the HMEI was not subject to a significant carcinogenic risk or non-carcinogenic hazard arising from exposure via both inhalation and ingestion of food. The additional lifetime carcinogenic risk arising from inhalation of metals was assessed using US EPA cancer potency factors and WHO guidelines, resulting in worst case estimates as summarised in Table 4.17. Arsenic is considered to be a possible oral carcinogen and therefore its potential carcinogenicity via ingestion of foods was also assessed. The results for both exposure routes were several orders of magnitude below the acceptable increment to a lifetime risk of 7x10-5.

Table 4.17: Health risk assessment results for Westbury works

<table>
<tr><th>Health effect</th><th>Tyres</th><th>Coal/pet coke</th><th>Criteria</th></tr>
<tr><td>Criskinh (lifetime)</td><td>2.4 x 10-8
(1 in 41,000,000)</td><td>4.0 x 10-9
(1 in 250,000,000)</td><td rowspan="3">7 x 10-5
(1 in 14,300)</td></tr>
<tr><td></td><td>5.9 x 10-8
(1 in 17,000,000)</td><td>1.9 x 10-8
(1 in 54,000,000)</td></tr>
<tr><td>Crisking (lifetime)</td><td>6.9 x 10-9
(1 in 146,000,000)</td><td>1.1 x 10-9
(1 in 946,000,000)</td></tr>
<tr><td>HIing</td><td>< 0.001</td><td>< 0.001</td><td>1.0</td></tr>
<tr><td>Dioxin (pg/kg/day)</td><td>0.03</td><td>0.06</td><td>1.0</td></tr>
</table>

The study also assessed exposure via ingestion of food. Doses of individual metals were compared with reference doses set by US EPA. For each metal, doses were at least 5,000 times less than those suggested for any discernible health effects when burning coal/pet coke only or when burning tyres. The assessment of health effects arising from ingestion of metals via food showed that emissions from the works did not pose a significant risk to health.

The potential health impact of dioxins was discussed by comparison with the TDI set by the WHO. The assessment showed that the HMEI daily intake would be 0.03 per cent of this TDI for tyre burning (0.06 per cent for coal/pet coke), even allowing for the conservative assumptions incorporated into the model. This daily intake would also be 0.14 per cent (tyres) and 0.24 per cent (coal/ pet coke) of the current daily intake of an average individual.

In summary, the results of the assessment suggest that burning of tyres is likely to:

- increase the lifetime carcinogenic risk of the HMEI from exposure to trace metals by a factor of three compared to the burning of coal/pet coke only, but this risk is several orders of magnitude below the acceptable increment to lifetime risk;

- decrease the lifetime non-carcinogenic risk of the HMEI from exposure to trace metals by 10 per cent compared to the burning of coal/pet coke only;

- decrease the incremental dose of dioxins and furans by 50 per cent.

The carcinogenic risk of some dioxins and furans is much higher than for each of the trace metals considered or the total for metals. Hence, the small increase in lifetime risk from trace metals is more than offset by the reduction in risk resulting from lower emissions of dioxins when burning tyres. Burning tyres as SF reduces the overall lifetime carcinogenic risk of the HMEI by a factor of 10.

4.2.8 Rugby

Cook and Kemm[40], on behalf of the local Primary Care Trust (PCT), carried out a HIA of the substitution of 40 per cent chopped waste tyres for coal in Kiln 7 at the Rugby Cement plant in Long Lawford, Rugby. The results of the assessment are summarised below.

- "Trace metals - tyres contain much more zinc than coal and emissions will increase, but are not expected to pose any significant health hazard based on the EAL for this substance. Emissions of most other trace metals are predicted to be unchanged or to fall.

- Dioxins - dioxin levels currently emitted from the stack are very low, which makes variations difficult to measure. Experience from other plants suggests that including tyres in the fuel does not produce a measurable change in dioxin emission due to the high incineration temperatures. While health effects of dioxin exposure are well recognised and while accumulation of dioxin in the environment is clearly undesirable, it seems unlikely that tyre burning in the kiln will contribute measurably to either.

- Particulates (PM10) - there may be a small increase, although main source of exposure is traffic (>70%). Particulate emissions are the most plausible way in which tyre burning might impact on health. In addition to the requirement for no environmental detriment, there should be a requirement that total particulates should remain well below the permitted level of 30 mg/Nm3.

[40] Cook A. and Kemm J. *Health impact assessment report on proposal to substitute chopped tyres for some of the coal as fuel in cement kilns*. 2002.

- NOx - tyre burning is likely to reduce NOx emissions from the plant, and therefore will have a positive health impact. The IPPC application for Cauldon predicts a likely reduction of NOx, supported in a review by AEA which found that NOx emissions diminished in three plants using tyres as a substitute fuel. Any change in emissions of NOx associated with a change in fuel at Rugby is likely to be downwards, and will thus exhibit a positive health impact.

- SO2 - there is likely to be no change in SO2 emissions with the change in fuel. Changes in the amount of SO2 being emitted from the kiln are not predicted, in which case there will not be any effect on health. Experience from other plants does not show a consistent change in SO2 emissions when tyres are burnt."

The impact assessment also assessed indirect health effects from tyre storage and transport, psychological distress and unidentified intermediate factors. These could have a positive or negative health impact. The pattern of plume grounding would not be affected by a change in fuel from coal to coal/tyre mix.

Experience from elsewhere in the UK (as cited in the HRA report) was considered by the author to suggest the following for the use of tyres: reduced NOx emissions, no clear change in SO2 and CO emissions, particulate emissions unchanged or increased, emissions of VOCs and dioxins probably decreased and zinc emissions increased (although not significantly with respect to the EALs for those substances).

Secondary liquid fuel

The SLF blend used by Castle Cement is known by the proprietary name of Cemfuel® and by LCUK as RLF. A review carried out on behalf of the Environment Agency[41] on the use of SLF in cement kilns showed there to be an overall reduction in environmental impact of the production process:

- "the data from cement kilns burning SLF show consistently that there is a reduction in the most significant emissions of NOx when this fuel is burnt, although trial results may sometimes indicate this change is within the range of uncertainty of the measurement techniques;

- emissions of SO2 mainly are reduced when SLF is burnt, although in one trial there appeared to be a small increase, but this was found to be within the uncertainty of the measurement technique;

- emissions of CO showed both increases and decreases during trials and this is thought to be related to other kiln operating conditions rather than the type of fuel being used;

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[41] Atkins. *Update on the international use of substitute liquid fuels (SLF) for burning in cement kilns*.

- particulate emissions both increase and decrease during trials, but often within the range of uncertainty of the measurement technique. However, in all cases the environmental impact was not found to be significant, irrespective of the fuel used;

- some variability in the emissions of other species such as metals, dioxins and VOCs was observed, but the levels were not found to be environmentally significant for either baseline of during substitute fuel testing."

These trial data show that the use of SLF results in a reduction in the emissions to air of the most environmentally significant species. There is no evidence of consistent or significant increase in the emissions of other species from the burning of SLF. The overall environmental impact is therefore generally reduced by the use of SLF. As such, any health risk associated with the emissions would be reduced.

4.2.9 Ribblesdale

A trial assessment (AEAT, 2000a) was undertaken for the burning of Cemfuel® at 40 per cent substitution at the Castle Cement Ribblesdale works. Based on analysis of monitoring data and theoretical arguments, the burning of 40 per cent Cemfuel® was found to be preferable to 100 per cent coal, although the difference was not statistically significant. All fuel mixes had similar effects and could not be discriminated from each other within the error of the assessment. All emissions (including trace metals), were regarded as insignificant, except for NOx and CO for both cases, and PM and SO2 for coal. Only NOx was identified as requiring further assessment.

The introduction of Cemfuel® was found to cause no statistically significant change in the level of dioxins and furans, with emissions well within authorised limits. US EPA (1994)[42] algorithms (considered to be best practice at the time) were used to calculate uptake of dioxins and furans from the food chain for the HMEI. The intake for coal burning only was calculated to be 0.5 pg/day, while for Cemfuel® the uptake was lower at 0.15 pg/day. Both these values were considered to be insignificant compared to UK average intake of 125 pg/day.

Ginns and Gatrell (1996)[43] looked at the respiratory health of 300 children attending primary schools near the Ribblesdale works at Clitheroe, Lancashire compared with that of 300 children in schools between nine and 19 kilometres away from the works. The aim of the study was to determine whether there was a higher incidence of respiratory ill health in children living near the cement works, and if so whether this was due to burning of 50 per cent SLF.

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[42] US EPA. *Estimating exposures to dioxin-like compounds – Vol III: Site-specific assessment procedures.* US EPA EPA/600/6-88/055Cc, External Review Draft, 1994.
[43] Ginns, S. E. and Gatrell, A. C. Respiratory health effects of industrial air pollution: a study in east Lancashire. *Journal of Epidemiology and Community Health* 50, 631-635, 1996.

The study and control populations were comparable in terms of response rates, gender and socioeconomic indicators. There was no significant difference in the incidence of asthma between the two areas when adjustment for hayfever was made, however the incidence of sore throats was significantly higher in the case area, a difference not explained by other factors. The results indicated that certain non-specific health indicators were more common in children living near the cement works. However, the authors concluded that it was not possible to draw firm conclusions as to whether the excess might be due to exposure to emissions from the site, as there were no epidemiological data predating the use of the SLF.

4.2.10 Ketton

Cemfuel® has been used at the Ketton works since the mid-1990s. Soil sampling was undertaken in the vicinity of the works to determine the potential for elevated levels of contaminants in soil due to emissions from the plant. Dioxin soil concentrations were all less than or similar to that found in typical UK soils (mean rural soil 3.4 ng/kg and mean urban soil 13 ng/kg). In three of the five samples, measured concentrations were found to be below that of the reagent blank, thus underlining the very low levels found. These low figures demonstrate that over sixty years of cement manufacture at Ketton works has had little or no impact on the level of dioxins in soil. In all cases, there were no elevated levels of any of trace metals.

4.2.11 Cookstown

Modelling was carried out to determine changes in ground level concentrations from using RLF at the Cookstown works. For the majority of pollutants, the difference in ground level concentrations between base case emissions and partial RLF fuel emissions was found to be very small. Increments as a percentage of EAL were less than one per cent for the long-term EAL and 20 per cent for the short-term EAL, with the exception of NOx. For NOx, however, there was an overall reduction in incremental annual mean concentrations of 0.8 µg/m3 and a reduction of 45 µg/m3 as the hourly average 99.8th percentile.

Refuse-derived fuel

4.2.12 Ketton

The Ketton works submitted an application for a variation to burn Profuel® as a partial replacement to coal in Kilns 7 and 8. The results of the HRA undertaken using HMIP methodology (as reported in the application) showed the uptake of dioxins through the food chain to be no different when either Profuel® or coal was used. In addition, this uptake was shown to be negligible compared to the UK average dietary intake of these compounds.

4.2.13 Padeswood

As discussed above for tyres, a general HRA was undertaken for emissions from Kiln 4 in comparison to Kilns 1, 2 and 3 at the Padeswood works. This showed that both the estimated incremental cancer risk and dioxin intake were well below guideline values. Therefore, based on the difference in emissions between the two sets of kilns and the difference in emissions between Kiln 4 baseline and with Profuel®, any change in health effects would be insignificant.

4.2.14 Westbury

RDF might possibly be used at the Westbury works. Based on the compositional analysis, it is not expected that emissions to air from the burning of this fuel would differ significantly from the existing case and therefore, RDF would not alter the baseline health risk.

Meat and bone meal

In power station trials in the UK, monitoring of stack emissions has shown that incineration of MBM would make no significant difference to emissions compared to normal coal-fired operation of a power station. SRM Research Group and UK Power Station Study both reported[44] that the incineration process resulted in a million-fold reduction in the risk of transmissible spongiform encephalopathy infectivity. The high combustion temperatures at which power station burners are operated are sufficient to destroy even the most heat resistant of conventional microbiological pathogens.

4.2.15 Ribblesdale

The dispersion of emissions from the kiln stack should not change following the introduction of MBM, thus impacts on air quality and human health should be unchanged from those presented in the air quality assessment included as part of the original PPC application for the Ribblesdale works.

Some information on the health effects of burning MBM is found in Castle Cement's application for a permit variation to burn MBM. The impact of the site whilst burning existing fuels (without MBM) was assessed in the application. Since a reduction in, or no change in, emissions was expected, the impacts on human health calculated as a lifetime cancer risk of one in 67,000,000 compared with the assessment criteria of one in 14,300 would be unchanged[45]. Given this extremely low level of risk, the health impacts were considered to be currently insignificant and will remain insignificant when MBM is used.

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[44] Department of Agriculture and Food, Ireland, Report of Inter-Departmental/Agency Committee on Disposal Options for Meat and Bone Meal (MBM), 2003.
[45] For further details, see ERM (2002).

4.2.16 Aberthaw

In a similar manner to all permits relating to the burning of MBM, the permit issued by the Environment Agency stipulated that MBM used at the Aberthaw works cannot be produced from the rendering of any animal waste from the OTMS designed to eliminate BSE, as long as the scheme remains in force. The waste for rendering may contain specified risk material such as brain and spinal cords from other animals.

The application for use of MBM at Aberthaw stated that the dispersion of emissions from the kiln stack would not adversely change following the use of MBM, indicating that the impact on human health and air quality would remain unchanged. This should be illustrated in the air dispersion modelling and COMEAP assessment to be carried out as part of the application.

Experience from Europe

Emissions monitoring carried out at ENCI Maastricht (reported in the Ribblesdale works IPPC permit variation application for use of MBM) showed that concentrations of all pollutants decreased, or remained below detection limits, during burning of MBM. The most significant reductions were total heavy metals (from 0.11 to 0.03 µg/m3), dioxins (from 0.06 to below 0.01 ng/m3), and SO2 (from 28 to 3 mg/m3).

The Department for Agriculture and Food in Ireland's Inter-departmental/ Agency Committee looked at disposal options for MBM and found co-incineration by the cement manufacturing industry to be the most practical recovery outlet. MBM could be used as a substitute fuel in cement kilns, with the resultant ash being incorporated in the final product. The report (Department of Agriculture and Food, Ireland 2003) cited a risk calculation carried out by the Agency which showed that the likelihood of the most exposed individual ingesting sufficient infectivity as a result of the burning of rendered material from OTMS in power stations (assuming that the entire throughput of the scheme were to be disposed of by this route) to be less than one in a billion years. This was reported as equivalent to a risk of one thousand times less likely than death by lightning. The risk to the average member of the public would be well below the risk to the most exposed person.

Recovered fuel oil

Most used or discarded oil from automotive, shipping and industrial lubricating applications is recovered and made into a fuel called RFO. Historically, RFO has found use in a number of industrial applications as an alternative hydrocarbon fuel to virgin fossil fuels such as oil or gas. It is very similar in composition and physical properties to the diesel light up fuel used in the cement industry.

4.2.17 Cauldon

Based on the compositional analysis of RFO presented in the application to burn RFO at the Cauldon works, it is not expected that emissions to air from the burning of this fuel would differ significantly from the existing case and therefore, there would be no significant change in the baseline health risk.

Processed sewage pellets

4.2.18 Cauldon

The Cauldon works is permitted to substitute up to 40 per cent (or up to 4.5 tonnes per hour) PSP. The application for permanent use of PSP reported that, in summary, NO2 emissions increased by three per cent while CO emissions increased by between four and seven per cent. These increases were within the measurement uncertainty associated with CEMs. Increases in SO2 emissions of eight per cent were due to raw material rather than fuel type.

There was no appreciable difference in TPM, VOCs, hydrogen halides, selected organics, PAHs, phosphorous, dioxins or trace metal (including zinc) emissions measured by extractive sampling during PSP trials compared with the baseline measurements. This suggests that the impact on human health would not be affected by the use of PSP as a SF.

Conclusions

Several air quality and health risk and impact assessments of the use of SFs as well as conventional fuels were reviewed here. These showed there to be, under normal operation, a negligible impact on the risk to human health due to the use of any SFs. Any change in health risk due to changes in ground level concentrations would not be detectable through any currently available health surveillance method.

Table 4.18 shows some of the risks to which the public is involuntarily exposed. The lifetime risk of someone in England and Wales contracting a fatal cancer is 0.2 or one in five. This is equivalent to an annual risk of one in 390 or 2.85 x 10-3, assuming an average 70 year lifetime. Therefore, additional risks due to exposure to pollutants when using SFs (in all cases, less than the HRA acceptability criterion for the increment to risk in cancer of one in a million) are extremely low compared with the national background annual cancer risk. Any change in health risk from the use of SFs, likely to be undetectable by normal surveillance methods, would not materially change an individual's risk of death.

Table 4.18: Annual and lifetime risk of death for various causes

Cause of death	Annual risk	Lifetime risk
Fatal cancer	1 in 390	1 in 5
All forms of accident	1 in 4,060	1 in 60
All forms of road accident	1 in 16,800	1 in 240
Lung cancer caused by radon in homes	1 in 29,000	1 in 400
HRA trigger figure (acceptability criterion)	1 in 1,000,000	1 in 14,300
Lightning	1 in 18,700,000	1 in 267,000

Source: HSE (2001)[46]

[46] HSE. *Reducing risks, protecting people: HSE's decision-making process*. Health and Safety Executive, Suffolk, 2001

The results of the COMEAP assessments reviewed here all fall within the range of results provided in a recent report by Defra[47] reviewing the environmental and health effects of waste management in relation to municipal solid waste and similar wastes. For incineration, the range of results provided in the report (Defra, 2004) was below 0.0000031 up to 3.0 health effects per year, including an overall uncertainty of a factor of 16.

This conclusion is in line with the opinions of COMEAP and the HPA, the latter having published in 2005 a position statement on the use of SFs in cement kilns (HPA, 2005). This states that:

- "The process environment means that substitute fuels are no more polluting to the environment than conventional fuels and for some key pollutants are actually less so… Cement kilns are only a very minor source of organic pollutants and dioxin emissions…. It is evident that cement kilns, if well managed and maintained, are efficient and effective processes for burning substitute fuels…. While changes in emissions do occur, they are modest and site specific. There will consequently be little change in the pollution levels in the air that people breathe, as this is largely determined by other sources such as traffic. We are unaware of any evidence that burning substitute fuel has caused adverse health effects."

Concerns have been expressed that increased emissions of fine particulate matter may increase health risks. The HPA is not aware of any evidence to support this and the available information indicates that particle emissions from a cement kiln will consist of larger particles than those typically found in air polluted by vehicle exhaust. City centres and other areas polluted by vehicle exhaust typically contain far higher concentrations of particles, including fine and ultrafine particles, than are likely to result from emissions of a cement kiln.

4.3 Odour

The use of SFs requires special precautions to minimise odours arising during the handling, delivery, storage and firing of these fuels. In order to minimise odour, the following typical precautions are taken:

- SLF handling: during offloading, SLF vapour is vented to the road tanker. During transfer to the kiln, vapour is discharged via an oil scrubber and carbon filter.

- MBM handling: material arriving by bulk lorry is transported via a fully enclosed mechanical conveying system to the storage silos. Any air displaced from the system during discharge of the MBM is either vented into the kiln firing system or vented through carbon absorbers before being released to atmosphere.

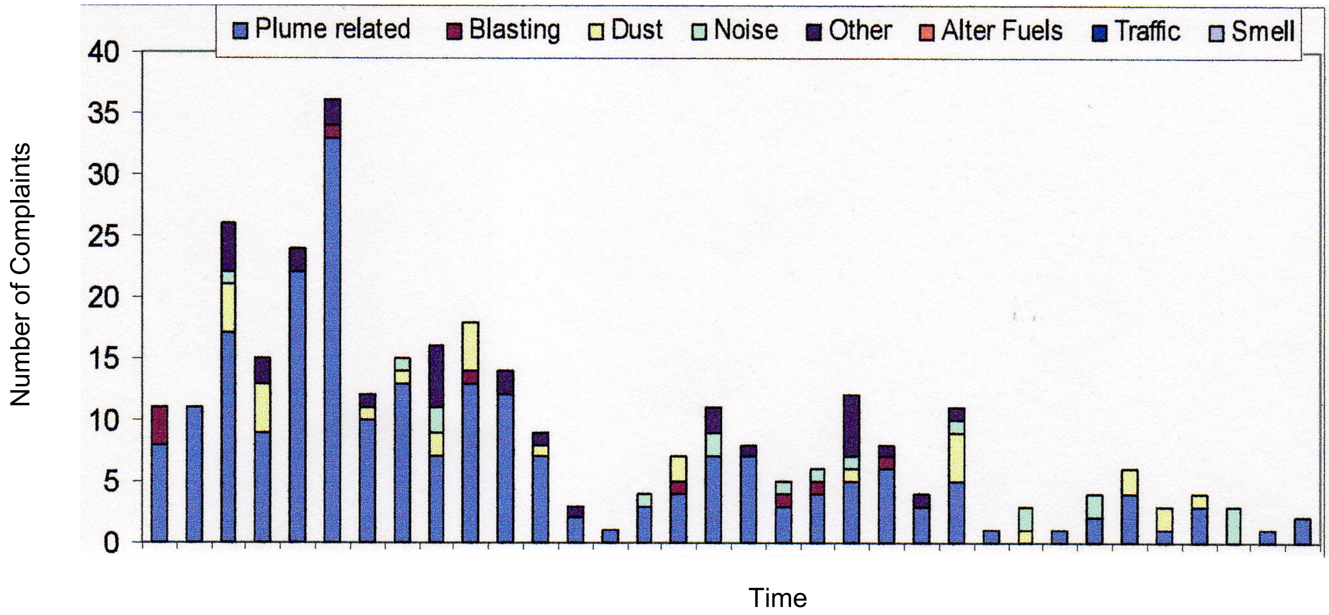
[47] Defra. *Review of environmental and health effects of waste management: municipal solid waste and similar wastes*. Defra, London, 2004

- PSP handling: the fuel transportation system used is a fully enclosed purpose built sheeted walking floor trailer. PSP transfer to the storage silo is via a totally enclosed system. The silos have to incorporate suitable explosion relief devices as standard.

The Hope works decision document (dated August 2005) which allowed the MBM trials to proceed, made reference to an odour issue. It was reported in the document that the Environment Agency was carrying out a separate NOX and SOX study. The only SF burned at this time was tyre chips. There was no firm evidence to support any claim that SF use contributed to odour problems.

The CSF review for the Ribblesdale MBM trial (April to October 2005) included an analysis of complaints arising from odour. Figure 4.4 shows the record of complaints at the Ribblesdale works on a monthly basis prior to and during the MBM fuel trials. SFs are shown as Alter fuels on the figure. The final seven months on the figure are the months in which the trials took place. As Figure 4.4 shows, the level of complaints had declined both before and during the trial. The conclusions in the trial report were that "at no point during the trial were any odours detected which could be attributed to the use of MBM on Kiln 7".

Figure 4.3: Complaints history at Ribblesdale works



4.4 Greenhouse Gases

The purpose of this section is to consider the impact of using SFs with a biofuel or partial biofuel rating on UK cement industry CO2 emissions. Although the use of biofuels has been reported in Asian lime plants, there is currently no use of these fuels in lime plants in the UK.

4.4.1 Comparison of carbon dioxide emissions and fuel efficiency of modern kilns

In this section, CO2 emissions from different dry process pre-calciner kiln systems are compared in order to demonstrate the effect of using SFs, including biofuels. Some typical benchmarking fuel consumption values are used in this process. Whilst these values may be slightly higher than some suppliers would claim, they are considered more realistic for actual annual fuel consumption as they include allowances for kiln start up conditions. The following assumptions have been made in the comparison:

- The kiln processes considered are all dry pre-calciner processes with two, three, four or five cyclone stages, designated SP2, 3, 4 or SP5.

- The wet process kiln system is not considered here, as a modern equivalent would be a pre-calciner process. The number of cyclone stages is set by the raw material moisture content. It is possible to increase the drying capacity of SP4 and SP5 processes by using the cooler exhaust gases in the raw milling circuit. This would be standard practice with SP2 and SP3 processes, as the associated drying capacity is limited.

- Typical fuel consumptions used include an allowance for kiln start up and shut down of an additional 20 net kcal/kg clinker. The additional annual quantity of fuel expended in kiln start up and shut down is generally between 15 and 30 net kcal/kg clinker, depending on reliability and consistency of performance.

- Organic carbon content in the raw meal is assumed to be 0.2% w/w.

- The cement additive rate (maximum addition to cement (MAC)) is maximised as far as possible, as this is the proven technique used to minimise the amount of CO2 produced per tonne of cement. This requires the production of a high quality clinker to permit the maximum MAC addition within the appropriate cement specifications standards.

- Emissions of CO_2 for each fuel type are in accordance with the World Business Council for Sustained Development (WBCSD) factors. The values for coal and petroleum coke are 93.6 and 93.8 kg CO_2 per GJ of fuel burned. There is no biofuel content for tyres, but there is an effective lower CO_2 emission with tyres due to the lower CO_2 allocation of 85.1 kg CO_2 per GJ fuel. The CO_2 emission value for MBM is 90 kg CO_2 per GJ fuel.

- For simplicity, the CO_2 evolved from raw materials is assumed to be a constant. Total CO_2 evolved from the fuels used is derived from simulated plant mass balances. Some of the organic carbon will convert to CO, however for simplicity it is assumed that all this carbon is converted to CO_2. A full VOC /CO/CO_2 balance would be needed to assess the actual quantities of CO_2 evolved for individual kilns.

Two theoretical cases for a one million tonne per year cement plant, which are representative of actual operational situations, are considered as follows:

- Case 1 – Firing 100% petroleum coke with no SFs.

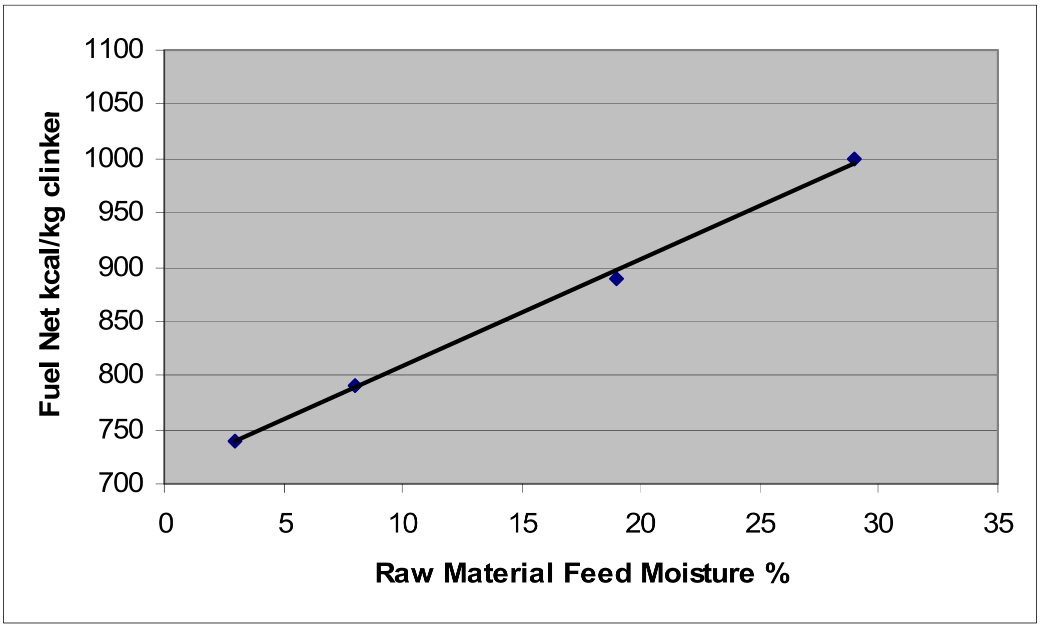
This case assumes that the total chloride input does not require a kiln bypass to be operated. It also assumes a simplified relationship between the number of pre-heater stages (SP2 to SP5) and the raw material moisture content.

- Case 2 – Firing 50% biofuel (MBM), 20% tyre chips and 30% petroleum coke.

This case assumes the need for 10 per cent kiln bypass to control chloride. The limit on MBM will depend on total P_2O_5 input and cement quality targets.

Figure 4.4 shows fuel consumption for different raw material moisture contents. The values of fuel consumption used in Case 1 are obtained from this figure. Figure 4.4 is based upon modern kiln processes handling wet raw materials, where the total fuel input is dictated by drying capacity considerations.

Figure 4.4: Fuel consumption versus raw material moisture content



Drying capacity may be enhanced by use of cooler exhaust gases and it has been assumed that the SP2 and SP3 pre-calciner kiln processes will use this approach as standard. Some recent SP4 projects also use the cooler exhaust gases to supplement drying capacity if the feed moisture is in the upper range noted in the theoretical cases.

Table 4.19 and Figure 4.5 show the results for Case 1, which involves no biofuels. All CO2 tonnages have been rounded to the nearest 1,000 tonnes per year.

Table 4.19: Case 1: 100% petroleum coke firing with no SFs, CO2 emissions from different dry process pre-calciner kilns

Pre-heater: number of cyclone stages	SP2	SP3	SP4	SP5
Fuel consumption (kcal/kg clinker)	1,000	890	790	740
Typical raw material moisture content	28 to 30% Ave 29%	17 to 21% Ave 19%	6 to 10% Ave 8%	2 to 4% Ave 3%
Type of raw milling	CD1	CD1	VSM1	VSM1
CO2 from fuel kg/kg clinker	0.392	0.349	0.310	0.290
CO2 from raw materials kg/kg clinker	0.551	0.551	0.551	0.551
Kg CO2 per kg clinker	0.944	0.900	0.861	0.842
Reduction in CO2 due to biofuels kg CO2/kg clinker	0.000	0.000	0.000	0.000
Overall net kg CO2/kg clinker	0.944	0.900	0.861	0.842
Annual tonnes per year CO22	837,000	729,000	752,000	732,000

Notes:
1. The raw milling system: CD = crusher dryer; VSM = vertical spindle mill. This selection has no impact on the CO2 emission, but it does affect the overall power cost as well as SO2 retention in the system.
2. The average cement to clinker ratio is 1.139 (range varies from 1.127 to 1.148).

Figure 4.5: CO2 by kiln process – no biofuel

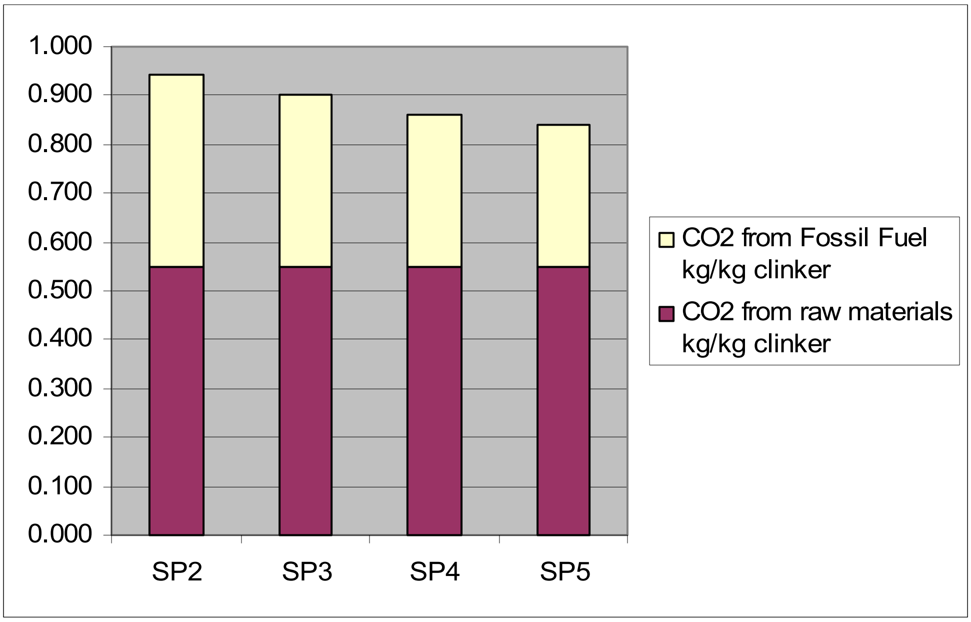


Figure 4.5 shows that the CO2 evolved from the raw meal remains constant for the four kiln processes when burning fossil fuels without a bypass. If a kiln bypass is required to control the chloride, alkali or sulphur inputs, the CO2 evolved from the raw meal will increase if the partially calcined meal is removed from the process.

Although wet process kilns are not included in this comparison, a typical CO2 emission value for a fossil fuel fired wet process kiln would be around 1.10 kg CO2 per kg clinker.

Table 4.20 and Figure 4.6 show the results for Case 2, which involves biofuels. All CO2 tonnages have been rounded to the nearest 1,000 tonnes per year. Table 4.20 shows that fuel consumption increases by 25 net kcal/kg clinker to allow for a kiln bypass. In Figure 4.6, the total CO2 (fuel and raw material) is shown together with the quantity of total CO2 allowing for CO2 emitted from biofuel (which is carbon neutral under the EU ETS) and the quantity of CO2 from the biofuel (i.e. carbon neutral).

Table 4.20: Case 2: 50% biofuel (MBM), 20% tyre chips and 30% petroleum coke firing

Pre-heater – number of cyclone stages	SP2	SP3	SP4	SP5
Fuel consumption (kcal/kg clinker)[1]	1025	915	815	765
CO2 from fossil fuel kg/kg clinker	0.197	0.177	0.158	0.148
CO2 from raw materials kg/kg clinker	0.562	0.562	0.562	0.562
Kg CO2 per kg clinker	0.991	0.945	0.903	0.882
Reduction in CO2 due to biofuels kg CO2/kg clinker	0.232	0.206	0.183	0.172
Overall net kg CO2/kg clinker	0.759	0.739	0.720	0.710
Annual tonnes per year net CO2[2]	647,000	627,000	609,000	600,000
Reduction in annual tonnes per year net CO2 by using biofuel[3]	190,000	165,000	143,000	132,000

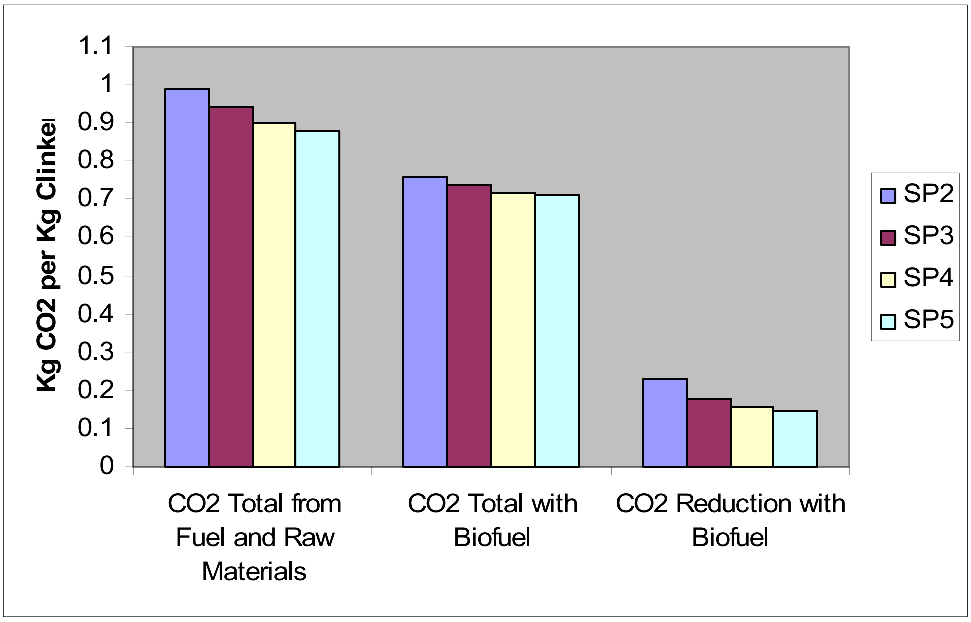
Notes:

1.Includes an allowance of +25 net kcal/kg clinker for kiln bypass. With a modern gas recycle system, this may be reduced to around 16 net kcal/kg clinker. The use of a kiln bypass system involves higher overall production of CO2 from the raw materials and fuels compared to the situation with a zero kiln bypass. This increase in CO2 is due to the loss of calcined material in the bypass dust, plus the additional fuel requirement for the bypass. Recovery of the bypass dust as an additive to the cement is one means of reducing the net effect of the bypass CO2 loss, but this is subject to cement quality considerations.

2.The average cement to clinker ratio is 1.179 (range varies from 1.173 to 1.184), hence a slightly lower quantity of clinker is required in order to make the one million tonnes per year of cement, with correspondingly less CO2 generated from the raw meal required for this clinker. The higher cement to clinker ratio arises from the use of lower sulphur content biofuel instead of higher sulphur content petroleum coke. The average sulphur content of MBM used in this example was 0.6 per cent compared with six per cent sulphur for petroleum coke. The use of MBM therefore results in a lower clinker SO3 content, requiring a slightly higher gypsum addition rate to the cement.

3.Difference between annual tonnes per year CO2 shown in Table 4.19 and annual tonnes per year CO2 shown in this table.

Figure 4.6: CO2 by kiln process – with 50% biofuel



Tables 4.19 and 4.20 and Figures 4.4 to 4.6 show the effects of using biofuel SFs in the cement-making process. The effects have been calculated for a range of pre-heater processes corresponding to the type of processes currently used in the UK.

A feature of the UK cement industry has been the need to design new pre-calciner kiln processes to suit the generally higher fuel consumption associated with having to dry relatively wet raw materials. In the case of the Rugby kiln, there are only two cyclone stages because the raw materials are comprised of slurry. The design for Medway works was a SP3 process. The Tunstead works would have normally been expected to be an SP5 process, had it not been for the need to handle some washed raw material. Padeswood Kiln 4 has a conventional SP5 process but this process is optimised to burn shale, which contains organic carbon, in the calciner.

If a standard plant size with cement production of one million tonnes per year is assumed, the reduction in the annual net CO2 emission from using up to 50 per cent biofuels would be between 190,000 (for SP2 process) to 132,000 tonnes per year (for the thermally more efficient SP5 process). With CO2 now becoming a tradable asset under EU ETS rules, the greater use of biofuel-type SFs such as MBM, PSP and (partially) RDF is becoming increasingly attractive.

Other benefits which can be achieved include a reduction in power consumption due to:

- reduced running of the fuel mill used for petroleum coke or coal grinding, resulting in savings in power costs;
- replacement of high sulphur petroleum coke by lower sulphur MBM/PSP/ RDF will reduce the clinker sulphate content and cement grindability (making it easier to grind). This will reduce the cement grinding energy costs.

Disadvantages of burning biofuel SFs include:

- the additional electric power and fuel costs associated with operating a kiln bypass system for chloride removal. This is subject to the base case chloride content of the raw materials or fuels used prior to SF use;
- associated dust disposal problems with high chloride dust, if this cannot be handled by the cement milling plant due to quality considerations;
- fuels such as MBM and PSP will have their maximum substitution rate dictated by what is considered to be the maximum limit for clinker P_2O_5.

Benefits clearly outweigh disadvantages and can be summarised as follows:

- reduction in purchased fuel costs;
- reduction in the net CO_2 emission from the plant;
- recovery of waste materials with energy production, plus recovery of fuel ash as a raw material;
- use of partial biofuels such as RDF helps councils to meet their obligations to reduce quantities of MSW to landfill.

4.4.2 Global warming potential

When addressing the effects of biofuels, a major consideration is assessment of CSFs. Several of the trials include consideration of the reduction in fossil fuel-derived CO_2. In the case of the Ribblesdale MBM trial, the CSFs included no net detriment to the local environment due to changes of emissions (CSF1), and a reduction in CO_2 (CSF2).

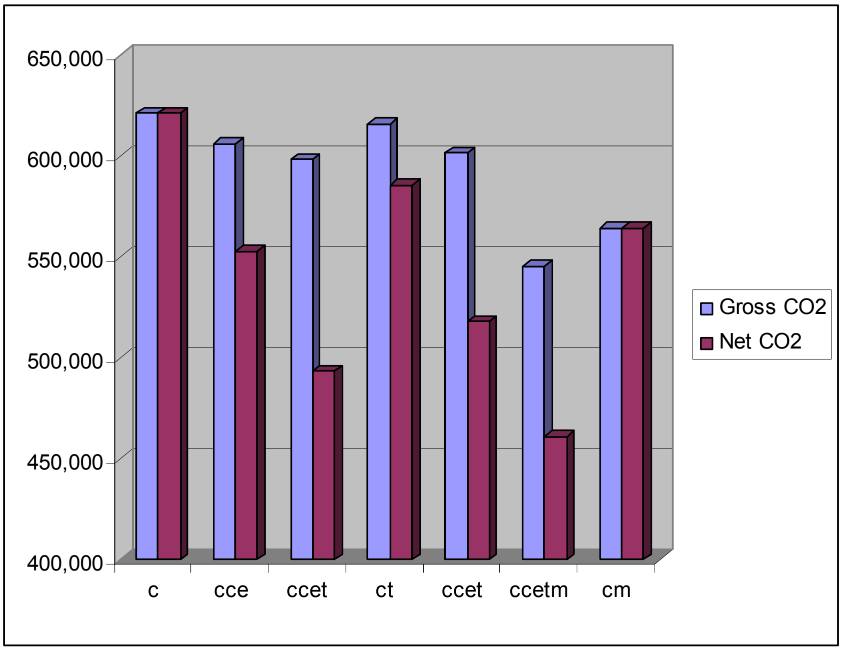
As part of the CSF2 assessment, the trial report includes details of the global warming potential (GWP) of different fuel mixes and shows the reduction in CO_2 achieved through the use of biofuels such as MBM. The results provided in the trial report are shown in Table 4.21 and Figure 4.7.

Table 4.21: Global warming potential using different fuel mixtures

Fuel case	Coal only	Coal Cemfuel ®	Coal Cemfuel ® tyres 2003	Coal tyres	Coal Cemfuel ® tyres 2005	Coal Cemfuel ® tyres MBM	Coal MBM
Figure 4.7 ref	c	cce	ccet	ct	ccet	ccetm	cm
Methane in VOC te/yr	81	80	18	18	24	38	34
GWP of methane te/yr CO2	1710	1677	369	369	503	805	704
Calcination te/yr CO2	395,097	395,097	395,097	395,097	395,097	395,231	395,231
Fossil fuel te/yr CO2	224,640	156,000	97,843	190,445	122,304	64,896	164,480
Alternative fuel te/yr CO2	0	53,475	104,997	30,303	83,778	84,708	0
Total fuel gross te/yr CO2	224,640	209,475	202,840	220,747	206,082	149,604	164,480
Total gross te/yr CO2[1]	619,737	604,572	597,937	615,844	601,178	544,835	563,711
Total net te/yr CO2[2]	619,737	551,097	492,940	585,542	517,401	460,127	563,711
Total gross GWP te/yr CO2[3]	621,447	606,248	598,306	616,213	601,681	545,640	564,416
Total net GWP te/yr CO2[4]	621,447	552,773	493,309	585,910	517,904	460,932	564,416

Notes:
1. Calcination + total fuel gross.
2. Total gross – alternative fuel.
3. Total gross + GWP of methane.
4. Total net + GWP of methane.

Figure 4.7: Global warming potential using different fuel mixtures



4.5 Energy Efficiency

4.5.1 Fuel consumption

Typical fuel consumption benchmarking figures for UK cement plants are provided in Tables 4.19 and 4.20. Typical fuel consumption for a wet process kiln would be around 1,250 to 1,350 net kcal/kg clinker, depending on the slurry moisture level. There was limited information within SF trial reports to assess the effects of burning SFs on overall fuel consumption with and without SF firing. However, the effects of burning SFs on the overall fuel consumption can be predicted from heat balance considerations.

The following are general notes on fuel consumption:

- replacement of higher quality fuels by lower quality waste fuels will affect the overall fuel consumption for the kiln process;
- an increase in the overall heat balance consumption may result from the following factors:
  - lower gross to net CV ratio which results in higher gross fuel consumption with associated higher waste gas heat losses;
  - high moisture in fuels (such as SLF) which contributes to higher waste gas heat loss in the form of steam;
  - reduction in flame emissivity in the burning zone may reduce the clinker output and kiln shell heat losses will then be higher;

- with certain fuels, such as high volatile content SFs, the additional volatile input may assist kiln burning conditions and offset some of the above factors;

- the additional heat input from SF burning may help to increase kiln capacity if the existing kiln is limited by fossil fuel capacity or any other limitations imposed by the kiln burner capacity. Fuels such as MBM, which do not require milling, can effectively uprate a calciner firing capacity.

The higher moisture in fuels will have the beneficial side effect of NOx reduction from a lower burning zone flame temperature. The disadvantage is that it may reduce heat exchange in the burning zone. Operational experience has shown that the higher moisture content of SLF can have a detrimental effect on kiln output. A well-known technique to increase kiln output limited by burning zone heat exchange is to use higher quality fuel, but this tends to increase NOx as well as operating costs.

4.5.2 Electrical power consumption

There is little information in SF trial reports on the effects of SF burning on overall power consumption. If it is assumed that overall power consumption to the clinker stage (SP5 pre-calciner kiln process) is 62 kWh/tonne clinker (a reasonable assumption based on information gathered on the various cement and lime plants), then power consumption for grinding 50 per cent coal and 50 per cent petroleum coke would be around 3.8 kWh/te clinker. Substitution of 50 per cent MBM would thus save around 1.9 kWh/te clinker.

Another factor affecting power consumption is that of cement grindability. High sulphur content fuels such as petroleum coke increase the clinker SO3 and cement grindability (making it harder to grind). A basic calculation of the effects of switching from 100 per cent petroleum coke firing to 50 per cent petroleum coke and 50 per cent MBM predicts a reduction in power consumption of the cement plant by approximately three kWh/tonne, as well as reducing the fuel milling power costs. This approximate figure depends on cement product mix and target cement surface area. However, the effects of using SFs on cement quality parameters (P2O5 and chloride content) must also be taken into account when assessing the effects of SF on energy consumption.

Overall assessment of plant fuel and electric power energy costs

As noted in Section 3, an overall technical and commercial evaluation of all interrelated factors affected by the use of SFs would be useful, alongside the normal evaluation of environmental impacts. Cement producers produce financial and environmental evaluations, but details of the latter are commercially confidential and the documents were not available to Atkins.

4.5.3 Waste

The use of SFs produces minimal related waste products, as the residual ash is retained in the clinker product. This can be particularly beneficial if residual ash from the SF can replace additives; for example, tyres contain iron which may replace expensive additives such as iron oxide. Some additional waste may arise from the use of SFs, such as contaminated rags and clothing, increased cement kiln dust and spillages. Contaminated rags and overalls may be burned on site or taken off site for disposal. If such contaminated items are burned, permission must be obtained from the Environment Agency to do so.

The use of kiln bypass systems allows a wider range of SFs to be used, by virtue of the ability to control the effects of chloride, alkalis and sulphur in the raw materials and fuels on the kiln process. The cement kiln dust produced by kiln bypass systems represents another waste, unless other disposal routes are available. Currently cement kiln dust is sent to landfill, although some is returned to the cement-making process or used in land reclamation (where its highly alkaline properties are welcomed to neutralise acid soils).

The recent MBM trial at the Ribblesdale works resulted in some increase in cement kiln dust. The trial report stated that at the time of writing approximately 2,300 tonnes of bypass dust had been extracted from Kiln 7 at an average rate of 7.5 tonnes/day. During the MBM trial, this increased to an average of 10 tonnes/day, with a peak figure of approximately 21 tonnes. The trial report stated that these higher figures were the effect of a trial to maximise the extraction rate from the system and were not considered as typical.

5 Conclusions

5.1 Conclusions

The main conclusions of this report are as follows:

- Tyres were one of the earliest substitute fuels to be used, due to their availability and their high calorific value. This was then followed by waste solvents (SLF), which are now the most used SFs in the UK. However, since 2002 RDF and biofuels such as MBM and PSP have been growing in use.

- The use of SFs in UK cement plants has accelerated with the modernisation of cement kilns such as Castle Cement, which has replaced five kilns with a single modern kiln. Modern pre-calciner kilns have the flexibility to burn the maximum quantity of substitute fuels, because they have the latest combustion control and efficient pollution control equipment.

- The substitution rate for cement kilns in the UK is below the average figure for Europe. The latest BCA data shows that SF use in the UK had grown to around 14 per cent in 2005. Cembureau data for other European countries for the period 2003-2004 indicated an average SF use of around 17 per cent.

- Assuming that the use of a SF meets environmental regulations, its use is driven by commercial and availability considerations.

- It may well be the case that cement plants are reluctant to commit to the use of a particular SF which may require significant capital investment, unless they are confident of its long-term availability and cost-effectiveness. Some cement companies have secured a share in SF producers to ensure a guaranteed supply.

- RDF, which includes a range of waste materials, can be processed to produce a high CV product that meets regulatory and industry standards. Waste disposal in the UK generates large quantities of materials that have the potential to be processed into a usable SF. However, the processing facilities to produce RDF commercially are still in the early stages of development in the UK, with such processing plants yet to become commonplace.

- The CEN/TC 343 committee is developing the relevant European standards for the market for solid recovered fuels such as RDF. This standardisation will enable the safe and efficient use of solid recovered fuels and will assist in developing the market and usage of such fuels.

- Prior to the use of SFs in cement kilns, a trial has to be carried out to demonstrate that when using SF, the plant meets environmental regulations. A thorough examination of the literature has found no examples of the prevention of use of SFs for environmental, planning or other reasons.

- From the results of SF trials examined here, the following observations can be made:

    - the burning of SLF, Cemfuel®, tyres and RDF can lead to a reduction in total emissions to air from cement kilns;
    - increments to long-term and short-term pollutant concentrations arising from cement kilns are small fractions of the AQS objectives, irrespective of whether conventional fuels or SFs are burnt;
    - under normal operation, there is a negligible impact on the risk to human health from the use of any of the SFs;
    - as a consequence of the introduction of WID, SNCR, which is part of a BAT consideration for controlling NOx emissions, has been installed in most cement plants,

Other conclusions arising from the report are shown below.

Use of SFs in the UK in 2005 amounted to 268,351 tonnes, at a thermal substitution rate of 14.3 per cent. The types of SF used have increased markedly since 1990, when use was limited to tyres. The actual tonnage used is less than the maximum specified in PPC permits for cement kilns. The total for the maxima is approximately 1,050,000 tonnes per annum, of which 370,500 tonnes are subject to successful trials.

The BCA forecast for growth in SF use envisages an increase by 2007 to 1,260,000 tonnes of SF excluding waste oils and 1,515,000 tonnes including waste oils. These figures will only be possible if cement producers can progress trials and secure SF supplies. The sector plan also envisages an increase in the use of SFs. The most recently published Cembureau data for 2004 showed an increase in the average thermal substitution rate in Europe to 17 per cent. Even in 2005, the substitution rate in the UK was below this average figure. It seems reasonable to expect that there will be future growth in MBM use and greater application of RDF in the UK.

The Environment Agency's CCS shows that there were no Category 1 incidents and only one Category 2 incident relating to cement works in 2005, which was not directly related to the burning of SFs. The majority of incidents in 2005 related to limit exceedances, with maintenance of plant and equipment failure being the next most frequent type of incident. The Environment Agency's National Enforcement Database showed that between 1999 and 2005, the only year in which there was a prosecution relating to cement plants was 2000, but that there were enforcement actions in all years apart from 2002.

A review of consultation responses to applications to use SFs showed that there were more responses from non-statutory consultees than from statutory ones. The majority of received comments addressed the following concerns: environmental impacts; public health concerns; possible odour nuisance; effects on the food chain; safety issues; and more general issues such as the justification for SF burning and the need to undertake an EIA. No preventions of the use of SFs for environmental, planning or other reasons were identified.

A considerable amount of effort has gone into ensuring safe procedures to cover all interrelated aspects of transportation, quality and use of SFs in cement kilns and ensuring that these are complied with. For SF delivery, this includes ensuring that the quality and quantities are auditable, and that procedures are in place to reject deliveries if strict parameters are not met.

Information gathered up to June 2006 shows that environmental studies on alternative uses of SF materials have focused on individual SFs. Therefore, it has not been possible to draw any conclusions on the use of SFs as a group in cement kilns. In addition, life cycle assessments have been undertaken for only a limited number of SFs and the results of these assessments are variable. For SLF, it was concluded that burning in cement kilns was preferable to disposal by incineration for almost every considered parameter. For tyres, retreading (where retreaded tyres demonstrate the same safety standards as new tyres) was found to provide the best or second best score in more of the impact categories than use in cement kilns, and for RDF none of the considered options was found to be globally advantageous.

Data for effects on the environment provided in SF trial reports on the burning of a single SF in cement kilns shows that the burning of SLF, Cemfuel®, tyres or RDF leads to a reduction in the total impact of emissions to air. For lime kilns, there are limited data relating to effects on the environment, but the key finding is that SLF burning leads to a reduction in NOx emissions.

Under the WID, cement kilns have been granted derogations for ELVs for SO2 and VOCs, where it has been shown that emissions of these substances do not result from incineration of waste, but arise from the raw materials for cement manufacture. Derogations have also been granted for ELVs for NOx, with values assigned for ELVs varying depending on the technology used at each plant. A timescale has been set to reduce ELVs that have been assigned. In the case of HCl, derogations have been granted to cover unavoidable operational circumstances. Operators of cement plants have chosen not to go above the 40 per cent level for thermal substitution of hazardous waste; above this level, different emission limits apply. SNCR, which is part of a BAT consideration for controlling NOx emissions, has been installed in most cement plants as a consequence of the introduction of the WID.

An evaluation of available ambient air quality data for works using SFs has shown no effect on measured concentrations that may be unequivocally attributed to a change in emissions from cement works from the use of SFs. In fact, there is little evidence of an influence of cement works emissions on ambient air quality monitoring data, irrespective of the fuel used. Monitoring sites near cement works generally show compliance with AQS objectives. Dispersion modelling studies also tend to confirm that increments to long-term and short-term pollutant concentrations are small fractions of the AQS objectives, irrespective of whether conventional fuels or SFs are used. There are no AQMAs in the UK designated as a result of the operation of cement works. In most cases, changes in stack emissions have been found to be small compared to the relevant ELVs.

HRAs reviewed here show there to be, under normal operation, a negligible impact on the risk to human health from the use of SFs. Any change in health risk due to changes in ground level concentrations would not be detectable through any currently available health surveillance method. Additional risks from exposure to pollutants when using SFs are extremely low compared to the national background annual cancer risk. Any change in health risk from the use of SFs would not materially change an individual's risk of death. The results of the COMEAP assessments reviewed here all fall within the range of results provided in a recent report by Defra reviewing the environmental and health effects of waste management in relation to municipal solid waste and similar wastes.

Use of SFs requires special precautions to minimise odours arising during the handling, storage and firing of these fuels. The use of SFs with a biofuel or partial biofuel content rating leads to a reduction in annual net CO_2 emissions from cement plants. Hence, with CO_2 becoming a tradable asset under EU ETS rules, the use of biofuels becomes increasingly attractive. SFs produce minimal related waste products, as the residual ash is retained in the clinker product. This is particularly beneficial if the residual ash replaces additives.

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7 Glossary

AAQuIRE	a regional air quality model
ADMS	an air dispersion model used to predict ground level concentrations of pollutants
AERMOD	an air dispersion model used to predict ground level concentrations of pollutants
AES	Analytical and Environmental Services
AQMA	Air Quality Management Area
AQMAU	Air Quality Modelling and Assessment Unit, Environment Agency
AQS	Air Quality Strategy
AS	air separate (pre-calciner process with tertiary air duct)
AWDF	agricultural waste-derived fuel
BAT	best available techniques
BCA	British Cement Association
BLI	Tarmac Ltd, Buxton Lime & Cement
BPEO	best practical environmental option (a term describing an option that meets a given set of objectives which provides the most benefit or least damage to the environment in the long as well as the short term)
BSE	bovine spongiform encephalopathy
Calciner	a process unit designed for calcination in both the cement and lime industries (calcination is the process of heating a substance to a high temperature, but below its melting or fusing point, to bring about thermal decomposition or a phase (solid, liquid or gas) transition in its physical or chemical constitution)
CCS	Compliance Classification Scheme
CEM	continuous emission monitor
Cembureau	European Cement Association
CICS	Common Incident Classification Scheme
Clinker	a term for the material remaining after the process of smelting a metal ore (clinker is an intermediate material used in the manufacture of cement)
CO	carbon monoxide (a greenhouse gas)
CO2	carbon dioxide (a greenhouse gas)
COMEAP	Committee on the Medical Effects of Air Pollution
Crisk	carcinogenic risk

CSF	critical success factor
CV	calorific value (used to define the amount of heat released during the combustion of a fuel or food)
Cyclone	a process unit used for separation (typically for the removal of particulates from a gas stream)
Dioxins	generic term for all polychlorinated dibenzo-p-dioxin and furans, which form a group of 210 closely related compounds (dioxins and furans have been shown to bioaccumulate in humans and wildlife)
EAL	environmental assessment level
EIA	environmental impact assessment
ELV	emission limit value
Emissivity	ratio of radiation emitted by a surface or a flame and the possible theoretical radiation
EPAQS	Expert Panel on Air Quality Standards
EQ	environmental quotient (EQNOx = environmental quotient for NOx)
EQair	environmental quotient for emissions to air
ERM	environmental resource management
ESP	electrostatic precipitator (a particulate collection device)
EU	European Union
EU ETS	European Union Emissions Trading Scheme
FLS	F.L.Smidth (cement equipment supplier)
FSA	Food Standards Agency
Furans	see dioxins
GBF	gravel bed filter
GHG	greenhouse gas
GJ	gigajoule
Group 1 heavy metal	
	mercury
Group 2 heavy metal	
	cadmium and thallium
Group 3 heavy metal	
	antimony, arsenic, lead, chromium, cobalt, copper, manganese, nickel and vanadium

GWP	global warming potential
gypsum	compound with the following chemical formula: CaSO4,2H2O (gypsum is mixed with cement clinker during grinding and retards the setting time of cement)
Hazardous waste	as defined in the Hazardous Waste (England and Wales) Regulations 2005, SI 894
HAZOP	Hazard and Operability Study
HBr	hydrogen bromide
HCl	hydrogen chloride
Heat and mass balances	an accounting of the heat (energy) or mass (material) entering or leaving a system
HF	hydrogen fluoride
HI	hazard index
HIA	health impact assessment
HMEI	hypothetical maximum exposed individual
HMIP	Her Majesty's Inspectorate of Pollution (now the Environment Agency)
HPA	Health Protection Agency
HRA	health risk assessment
HSE	Health and Safety Executive
IEI	integrated environmental index
ID	induced draft
ILC	in line calciner
ing	ingestion
inh	inhalation
Interlocks	see safety interlocks
IPC	Integrated Pollution Control
IPPC	Integrated Pollution Prevention and Control (as implemented in England and Wales by the Pollution Prevention and Control (PPC) Regulations)
IPPC permit	a permit as issued under the Pollution Prevention and Control (PPC) Regulations
kcal	kilocalorie
kg	kilogram
km	kilometre
kWh	kilowatt hour
LCUK	Lafarge Cement UK
Lepol process	process in which the raw meal is nodulised, using the minimum

	quantity of water necessary, and the nodules fed directly to a horizontal travelling grate pre-heater in front of the rotary kiln
LEV	local exhaust ventilation
Lidar	light detection and ranging technique
LP	low pressure (drop cyclone design) (a feature of modern pre-heater designs and kiln modernisations)
m	metre
m3	cubic metre
MAC	material addition to cement (additives to cement such as limestone)
MBM	meat and bone meal
MBT	mechanical biological treatment
MDF	medium density fibreboard
Meal	the raw materials once they have been dried and ground into a fine powder
mg	milligram
MJ	megajoule
MSC	multi-stage combustion (used for NOx reduction)
MSW	municipal solid waste
NETCEN	National Environmental Technology Centre
ng	nanogram
Nm3	cubic metre of gas at a temperature of 273 Kelvin and a pressure of 101.3 kiloPascals
NO	nitric oxide
NO2	nitrogen dioxide
NOx	oxides of nitrogen (the sum of nitric oxide (NO) plus nitrogen dioxide (NO2))
NWP	numerical weather prediction
OCDS	Older Cattle Disposal Scheme
OTM	over thirty months
OTMS	Over Thirty Months Scheme
P2O5	phosphorus pentoxide (often used as a drying agent)
PAH	polycyclic aromatic hydrocarbon
PEC	predicted environmental concentration (of pollutants)
PC	process contribution (of pollutants)
PCB	polychlorinated biphenyl (a persistent organic pollutant)

PCT	Primary Care Trust
PDF	packaging-derived fuel
PEF	process engineered fuel
Petroleum coke	a carbonisation product of high-boiling hydrocarbon fractions obtained in petroleum processing (a general term for all special petroleum coke products such as green, calcined and needle petroleum coke)
pg	picogram
PM2.5	particulate matter with an aerodynamic diameter of less than 2.5 microns
PM10	particulate matter with an aerodynamic diameter of less than 10 microns
ppb	parts per billion (or µg/kg)
PPC	see IPPC
PPF	paper and plastic fraction
ppm	parts per million (or mg/kg)
PSP	processed sewage pellets
RBC	Rugby Borough Council
RCEP	Royal Commission on Environmental Pollution
RDF	refuse-derived fuel
REF	recovered fuel
RFO	recovered fuel oil
RLF	recycled liquid fuel
Safety interlocks	safety system that prevents feed to the kiln if conditions are not suitable
sd	standard deviation
SDF	solvent-derived fuel (lime sector term for SLF)
SDL	Steetley Dolomite Ltd
SER	Sapphire Energy Recovery
SF	substitute fuel
SFP	Substitute Fuels Protocol (produced by the Environment Agency)
SLC-D	separate line calciner-downdraft (a type of pre-calciner kiln system)
SLF	substitute liquid fuel
SNCR	selective non-catalytic reduction (a NOx reduction technique)
SO2	sulphur dioxide (a gas that reacts with water and atmospheric oxygen to form sulphuric acid (H2SO4) and thus acid rain)

SO3	sulphur trioxide
SP	suspension pre-heater
SP2,3,4,5,6	when SP is used with a number, it refers to the number of pre-heater cyclone stages used in either a pre-heater or pre-calciner kiln process
SRF	solid recovered fuel
SRM	solvent resource management
TDI	tolerable daily intake
te	metric tonne
TEQ	toxic equivalent value (used to express the measurement of a range of selected dioxins and furans in terms of the most toxic dioxin; 2,3,7,8,-tetrachlorobibenzo-p-dioxin)
Thermal substitution rate	percentage of thermal energy produced by alternative fuels
TOC	total organic carbon
TPM	total particulate matter
UK	United Kingdom
ultimate analysis	quantitative analysis in which percentages of all elements in the substance are determined
US EPA	United States Environmental Protection Agency
VCM	vinyl chloride monomer
VOC	volatile organic compound
Volatilise	to make volatile; to cause to pass off as a vapour
VSM	vertical spindle mill (used mainly for coal or slag milling in UK, but also used for cement grinding overseas)
v/v	volume for volume
WBCSD	World Business Council for Sustained Development
WHO	World Health Organisation
WID	Waste Incineration Directive (Directive 2000/76/EC of the European Parliament and Council on the incineration of waste)
WML	Waste Management Licensing
w/w	weight for weight (%) basis used for composition
μg	microgram

We are The Environment Agency. It's our job to look after your environment and make it **a better place** – for you, and for future generations.

Your environment is the air you breathe, the water you drink and the ground you walk on. Working with business, Government and society as a whole, we are making your environment cleaner and healthier.

The Environment Agency. Out there, making your environment a better place.

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