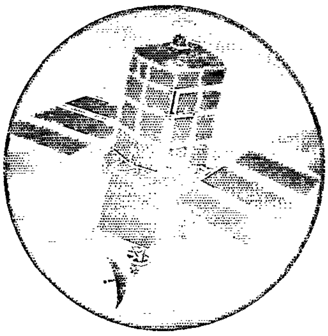
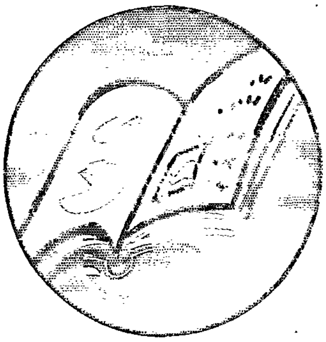
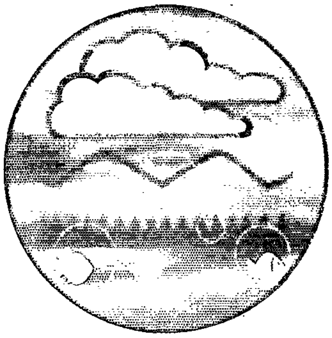
Substitute Liquid Fuels (SLF) Used in Cement Kilns - Life Cycle Analysis







Research and Development

Technical Report
P274

ENVIRONMENT AGENCY

Substitute Liquid Fuels (SLF) Used in Cement Kilns - Life Cycle Analysis

R&D Technical Report P274

Research Contractor:
Chem Systems Ltd

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This report summarises the findings of research carried out to provide information on the Life Cycle Analysis of Substitute Liquid Fuels used for burning in cement kilns. This information within this document is for use by Environment Agency staff and others involved in the management of Process Industries Regulation.

Research contractor

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CONTENTS

List of Tables

List of Figures

EXECUTIVE SUMMARY

Organic wastes are currently blended to form Substitute Liquid Fuel (SLF) for use in cement kilns. Although subject to strict regulation by the Environment Agency, there are concerns relating to the use of SLF. Chem Systems was commissioned to review the position of the SLF route in the environmental hierarchy using Life Cycle Assessment methodology. A further aspect of the study was whether SLF draws material from recycling or hazardous waste incinerators for economic reasons.

Waste Arisings

Wastes suitable for blending into SLF arise from several sources. Solvent wastes are produced by fine chemical producers and by industries using solvent-based products, such as coatings. Process wastes occur in the chemical and other process industries. One potential contributor to SLF is waste lubricating oil, which is used in cement kilns in Germany but not the UK.

Material currently being blended into SLF includes a wide range of compositions from which the SLF blend specification is compiled. Some wastes are largely aqueous and some have high halogen or metal contents.

Life Cycle Assessment (LCA)

In the LCA, the environmental burdens of sending one kilogram of organic waste to different disposal routes are considered.

The SLF option is preferable to hazardous waste incineration for most parameters. This is because the SLF replaces conventional cement kiln fuels, coal and petroleum coke. From data available, the SLF route can result in somewhat higher emissions of inorganic halogen compounds and semi-volatile and volatile metal compounds than incineration, though this might depend on the total quantity and retention is in any case high in both disposal options.

Recycling of solvents is environmentally preferable to incineration on almost every count. Recovery of solvent to leave a dry residue is preferable to recovery at 60-70 percent with incineration of residues. However, recycling does not necessarily show a consistent environmental advantage over sending SLF to cement kilns. This depends on the solvent.

Incinerators are designed for very high retention of certain contaminants, such as sulphur or halogens. The retention in cement kilns, although high, may not be as good. If the concentration of such contaminants in a unit of SLF is particularly high, then the other advantages of the SLF route may be outweighed. Tentative suggestions are therefore made in the report for contaminant levels at which wastes should be excluded from SLF. Administration of such an exclusion scheme would be difficult, however.

Economics

The analysis of economics suggests that it is more attractive to recover solvents than to blend the total waste into SLF. However, the use of SLF as a disposal route for solvent recovery residues can confer a competitive advantage over other recyclers. This route could compete in some cases with recovery to dryness.

SLF blenders are able to charge very much lower gate fees than the usual fee targets of incinerators.

Chem Systems has been unable to identify evidence to demonstrate that SLF has taken feedstock from solvent recycling or, to a damaging extent, from incinerators.

Quantities

Estimates have been made of the quantity of organic wastes in the UK that would be candidates for SLF, and the maximum possible demand for SLF cement kilns. The potential demand for SLF is a very significant part of total arisings, and substantial in comparison with current incinerator capacity. Current indications are, however, that cement producers would not choose to use SLF to this maximum extent.

KEYWORDS

Substitute Liquid Fuels, SLF, cement kilns, combustion, waste, co-incineration, hazardous waste, Life Cycle Analysis, recovery, solvent, recycling

1. INTRODUCTION

1.1 Background

There are three companies producing cement in the UK: Blue Circle Cement, Rugby Cement, and Castle Cement. The fuel used in cement kilns represents a large proportion of the variable costs of production. There are economic attractions in using waste as fuel. Various sorts of waste can be burnt, including tyres, plastics, and liquid organics. This report relates to Substitute Liquid Fuels (SLF) that are blended from many different organic wastes.

The burning of SLF in cement kilns is widespread in Europe and the United States. The Environment Agency has authorised the use of SLF in a number of UK kilns, after extensive trials were conducted and specifications for SLF were established for each plant. There are four main suppliers of SLF in the UK:

- SARP UK/Organic Technologies Limited, which also operates a waste incinerator and solvent recycling (SARP UK was formerly Leigh)
- Solrec, which also recycles solvents and has an on-site incinerator
- CMR, which also recycles solvents
- Safety Kleen, which focuses on the collection of wastes from small operations such as garages.

The companies have commercial arrangements with some waste suppliers as well as with the kiln operators.

1.2 Objectives of study

The House of Commons Environment Committee Report on the Environment Impact of Cement Manufacture was published on 5th March 1997. Recommendation 7 stated that "Our evidence indicated that as a result of the SLF programme, a considerable amount of solvent is being moved up the waste hierarchy, both from disposal to energy recovery and from disposal to materials recovery. The diversion of materials from landfill is to be welcomed. However, the situation is not at all clear and we are concerned that if the use of SLF expands in the future, large quantities of recoverable solvent might be diverted into SLF". Recommendation 8 specified that "the Environment Agency should investigate the extent to which "closed loop" solvent recovery had declined as a consequence of the SLF programme. When making decisions, the Agency should have regard to their likely effects on the movement of wastes up and down the waste hierarchy". The Agency agreed that such research will seek the preferred environmental solutions and will include investigation of "closed loop" solvent recovery compared with energy recovery, the source and types of wastes that are generated and their disposal routes. The study is aimed at fulfilling that commitment.

The objectives of the study are:

- to provide information on the sources, composition and volumes of materials used to make SLF
- to evaluate environmental options and especially identify those waste streams that are unsuitable for blending in SLF
- to assess the extent to which large quantities of recoverable wastes might be diverted into SLF in the future and the trend historically.

1.3 Study outline

The study consists of the following parts:

- **Section 3**: a review of the type of wastes used in SLF and their compositions, with a commentary on quantities arising
- **Section 4**: an environmental Life Cycle Assessment to compare the SLF route with recycling and incineration, leading to possible conclusions on wastes to be excluded from SLF
- **Section 5**: an analysis of the economics of disposal routes and recycling, plus a review of future trends
- **Section 6**: conclusions.

2. WASTE STREAMS

2.1 Sources

2.1.1 General

Wastes used in the preparation of SLF arise from many sources. The main categories of waste and the industries from which they originate are noted below. In Section 3.2, illustrative compositions of different wastes used in SLF are presented. Broad estimates of available quantities are given in Section 3.3.

One element of methodology in this report should be noted. For any type of source of waste, the exact chemical constituents and the composition can vary very widely. For example, wastes might be almost all liquid organics, or may be aqueous washings. One of the purposes of this report is to assess whether any wastes should be excluded from SLF on environmental grounds. It is simply not meaningful, because of the variability in composition, to base such recommendations on generic definitions of waste type or source. Any exclusions must be based on chemical analysis and other properties such as energy content. For this reason, exact characterisation of individual wastes is less important than broad definitions and trends.

2.1.2 Types of organic compounds

The wastes that are candidates for SLF are combustible because they contain organic compounds. These organic compounds fall into several categories.

Solvents

Solvents are organic compounds used for dissolving other materials. They are used in three ways:

- as part of a formulated product from which the solvent is intended to evaporate on use

- to dissolve contaminants in cleaning operations

- to facilitate chemical processes.

Chemically, solvents may be broadly categorised as hydrocarbons – both aliphatic and aromatic, oxygenates, and chlorinated solvents.

The main commercial solvents are listed in Table 2.1. There are many other compounds that can be used as solvents but that tend to be more limited in their use.

Table 2.1 Commonly used solvents

Hydrocarbons: Aliphatic	White spirits SBPs[1] and others
Hydrocarbons: Aromatic	Toluene Xylenes C_9+
Alcohols	Methanol Ethanol Propanol (e.g. IPA[2]) Butanols (n- and i-)
Other oxygenates	Glycol ethers Ether esters Esters Acetone (DMK) Methyl ethyl ketone (MEK) Methyl i-butyl ketone (MIBK)
Chlorinated solvents	Methyl chloride Methylene chloride Chloroform Perchloroethylene Trichloroethylene

[1] *SBP =Special Boiling Point*

[2] IPA = Isopropyl alcohol

Solvents from all sources are one of the main constituents of SLF in the UK.

Other working fluids

Many working fluids fall into the general category of lubricants and related products. They are used as lubricants, as transmission media such as brake fluid, for purposes such as cutting fluids, and as dielectrics.

Petroleum-based materials are produced by further processing of heavy process streams on oil refineries. The processing involves refining, deasphalting and dewaxing. These materials are therefore substantially heavy hydrocarbons, though the final products may contain various additives.

Synthetic lubricants and related products are also needed to respond to the extreme conditions in many modern applications. While some synthetic lubricants are hydrocarbons, most are organic compounds of a different kind.

These include the following:

- **Polyether oils** include aliphatic compounds such as polyethylene glycol polypropylene glycol and related esters and esters, used in applicants that include brake fluids, metal cutting oils, and special lubricants. They are miscible with water to varying degrees. Aromatic compounds, or polyphenyl ethers, are also produced.

- **Ester oils** are esters of carboxylic acids, and are used as jet engine lubricants etc.

- **Phosphoric acid esters** (with alcohols or phenols) are used as fire resistant fluids, plasticisers, and lubricants.

- **Silicone** and related compounds include silicone oils, which contain alkyl or aryl groups.

- **Halogenated** compounds include chlorinated paraffins and other chlorinated material. Environmental pressures have acted against chlorinated materials in some areas. Fluorinated compounds can be very effective and stable lubricants.

Fuels

Liquid fuels may report to waste streams if heavily contaminated. The organic chemical compounds are primarily mixed hydrocarbons, plus some oxygenates such as MTBE (methyl tert-butyl ether).

Biomass

Biomass is a possible type of organic waste, originating from, for example, processing of food and drink or as sludge from wastewater treatment. The main organic constituents will be primarily compounds such as cellulose, fat and proteins.

Other chemicals

"Other chemicals" covers an almost unlimited range of compounds that are used in the manufacture of chemical products or form part of chemical products. In addition to the compounds mentioned above, as solvents or other working fluids, there are biocides, pharmaceutical actives, pigments and dyes, surfactants and other detergent components, plastics or resins, and many specialised performance chemicals such as fire retardants or plasticisers, plus all the intermediates associated with production.

The range of compounds is too wide to be characterised. It includes aliphatics, aromatics and polyaromatics, and compounds with oxygen, nitrogen, sulphur, phosphorus, halogens and many other elements.

2.1.3 Generic types of waste source

The organic compounds can arise as wastes in several basic ways.

- Working fluids such as solvents or lubricants may become contaminated, degraded or diluted and be unfit for use.

- Some processing operations produce by-products for which there is no technically or economically feasible method of use or recovery.

- Similarly, heavy residues from distillation processes may find no beneficial use if they cannot be processed for further chemical recovery, or if they are contaminated.

- Aqueous effluents with high organic contents occur particularly in processes where water is present in the processing operations, perhaps as a medium or a reaction product, and whether the organic compound is miscible with water. Other sources, such as direct contact barometric condensers, can often be eliminated by redesign.

- Waste feedstocks, reagents, intermediates, and products can arise for many reasons, including when they are out-of-date, off-specification, or contaminated.

- Sludges, such as from tank cleaning, will be largely the stored organic compounds contaminated with polymerised material, water and scale.

- Material from clean-up operations includes aqueous equipment washings, floor washings, and wipings. It can occur in circumstances such as maintenance, grade change, disinfection or spills and leaks.

- Residual material can be left in containers such as drums or cartridges.

- Wastewater treatment sludge, particularly from biological treatment, is one source of relatively large volumes of organic waste from some plants.

Waste streams usually contain contaminants in addition to the main organic compounds and water. The contaminants depend upon the type of industry from which the waste arises. The main industrial sources of relevant organic wastes are reviewed in the following sub-sections.

2.1.4 Oil refining

The main sources of incinerable organic waste, apart from domestic and general waste such as packaging, are:

- sludge from phase separation and chemical treatment stages of effluent treatment; petroleum material from phase separation is typically recovered in a slop oil system on the refinery

- sludge from biotreatment of effluent

- tank bottom sludge and other oily sludges

- small (and diminishing) quantities of acid tars

- contaminated soil.

Total sludges typically amount to around 0.2 percent of refinery throughput. The effluent treatment sludges are typically landfilled or incinerated on site. Where recovery of hydrocarbon values from oil sludges is not feasible, incineration or use as fuel are suitable disposal routes.

Although the quantities of organic wastes from refineries are large, often several thousand tonnes per year at a big refinery, this does not feature as a major source of SLF or, largely, of feed to merchant hazardous waste incinerators. Spent reagent sludges and difficult tars for which destruction is the best option can be produced, however.

2.1.5 Commodity petrochemicals

Hydrocarbon feedstocks such as naphtha or reformate provide the source of petrochemicals. Basic building block chemicals are lower olefins, produced in steam crackers, and aromatics (BTX, or benzene, toluene and xylenes), extracted from reformate and other streams. Downstream production steps lead to chemicals that are products for industrial customers – such as solvents, surfactants, or commodity thermoplastics – or intermediates for use by others.

There are around 100 to 150 plants in this category in the UK, depending on how "commodity petrochemicals" are defined. Capacities range from around 30 000 tonnes per year to over one million tonnes per year. Processes are either continuous or, as with some of the polymer plants, continuous with batch reaction sections.

Few of these processes use the common commercial solvents described in Section 2.1.2, so solvent wastes are relatively rare in this sector. Specialised proprietary solvents are used in extraction of aromatics, for example, and are recycled and regenerated on site.

Because of the large scale of the plants, and their continuous nature, petrochemical plants are of highly integrated designs. By-product streams tend to be consumed as fuel if beneficial recovery of chemical value is not possible. Light ends from steam cracking of naphtha is an example. The plants also are usually connected to a wastewater treatment systems which can accommodate wash water unless in exceptional quantities or pollutant loading.

Apart from effluent sludge, organic wastes include:

- by-product streams
- heavy residues from continuous or batch distillation
- sludges with organic content plus acid or alkali, from treatment processes such as caustic waste
- organic slop with water
- spent residues of reagents such as DEA (diethylamine) or process-specific solvents.

Catalysts are often used in fixed bed systems, so catalyst residues are often a separate solid stream. However, dispersed catalyst systems may result in catalyst sludges, and traces of catalysts may also be present in other process wastes. In addition to organic compounds such as peroxides, or inorganic acids, catalysts many include metals or compounds of nickel, palladium, platinum, chromium, cobalt, molybdenum, aluminium and others.

The quantity of wastes for disposal offsite is usually small relative to production: typically 0.02 to 0.2 percent. This equates to a few tonnes per year to several hundred tonnes per year. At the larger end, the waste is transported in road tankers, while small quantities are drummed. Where waste quantities are larger, such as generation of chlorinated residues in ethylene dichloride/vinyl chloride production, plant-based solutions are more usual.

In some cases, an unrecoverable side stream may constitute a waste that must be exported for appropriate treatment or disposal. This may reflect the chemical composition of the stream or other regulatory considerations that cause it to be classified as a waste. One large source in this category is that from adipic acid production. The by-product stream, currently between ten and twenty thousand tonnes per year, contains several hundred parts per million of chromium and a few percent of boric acid, This is the largest single source of SLF at present.

2.1.6 Manufacture of resins and elastomers

This section of the chemical industry is described separately because it has some commonality of scale and character. Resins include polyester/alkyl resins, epoxy resins, formaldehyde-based resins, polyamides, amino resins, emulsion polymers and phenolics. The products are used in a wide variety of applications including coatings, wood glue and sealants. Elastomers include synthetic rubbers such as SBR and NBR.

Production is typically on a batch basis, with addition of metered reagents to a reactor, reaction with appropriate processing such as heating under reflux, finishing and packing in drums or other containers. With several types of resin product, the resin is carried in a solvent such as styrene or xylenes, or as an emulsion or other water-compatible form. Capacities range from typically several hundred tonnes per year to around 50 000 tonnes per year of finished product.

Wastes arise as:

- used reagents
- aqueous streams with reagents or solvents such as phenol or methanol
- filter residues with high solvent contents
- resin sludges and distillation residues
- waste solvents.

The aqueous streams with significant quantities of organics are produced in reasonably large quantities, often 1 000-5 000 m^3 per year. The organic content may range from around one percent to 30 percent or more. At the lower end of the organic range, biotreatment with suitably acclimatised cultures may be feasible. If no on-site treatment – such as incineration – is available for more concentrated wastes, the waste is taken away in road tankers.

The liquid and sludge wastes typically amount to a few hundred tonnes per year from the larger plants, or under one percent of production. This material is typically drummed. Some solvent recovery is performed on the waste solvent streams.

2.1.7 Manufacture of fine and performance chemicals

Manufacture of fine and performance chemicals covers a very wide range. Even within a sub-sector, such as pharmaceutical actives, there is a spread of capacity from a few kilograms to a few tens of thousands of tonnes per year and a variety of chemical products and synthesis routes. One producer reported hundreds of products and a list of special waste arisings that ran to 50 pages. Generalisation here is even more difficult than in other industrial sectors. Examples of waste streams are mentioned in the text when data were obtained for specific companies.

Process technology is typically based on batch reactors plus associated unit operations such as distillation, solvent extraction, filtration and drying. Reaction yields may be low, and it is often not technically or economically feasible to recover or use the reagents or by-products.

This sector is one of the largest consumers of commercial solvents, which are used to facilitate reactions and extractions. The solvents used in largest quantities are alcohols, ketones and esters. However, almost all types are employed somewhere in the sector. Chlorinated solvents such as methylene chloride and chloroform are used in moderate quantities.

Sources of organic wastes, other than wastewater treatment sludges, include:

- spent solvents, contaminated either with process material and residues, or because they are a mixture of different solvents
- residues from solvent recovery stills
- streams with by-products or unrecoverable reagents, often aqueous, such as mother liquors
- distillation residues (non-solvent)
- equipment washings, floor washings, etc
- off-specification batches or old stock.

All these types of waste were identified in information obtained on around 20 fine chemical plants. The chemical compounds present and the waste composition are specific to each plant. Examples are tabulated in Section 2.2. The organic contents vary from a few percent in water to substantially 100 percent organics. The solvents wastes include many of the commercial solvents as noted above. Other compounds vary too widely for general comments to be meaningful. They include halogenated material, aromatic and poly-aromatic compounds, organics with nitrogen and sulphur. Few producers quote more than trace quantities, or at most a few hundred parts per million, of metals.

Waste quantities per site range from around one tonne per year to two thousand tonnes and more, not necessarily in inverse proportion to concentration (i.e. the large quantities are not necessarily aqueous). Quantities of up to around one hundred tonnes per year tends to be drummed waste; larger amounts are typically taken in road tankers.

Incineration is the most frequently used form of disposal for the waste examined. In-house incinerators are used for large quantities, usually a few hundred tonnes per year at least. When the process requires a vents incinerator, there can be synergy in also incinerating liquid wastes. Heat recovery can offset economics. Companies with in-house incinerators export to merchant incinerators when the waste is not suitable for the in-house equipment. Reasons may be regulatory – if the in-house incinerator is not authorised for halogenated waste, for example – or technical. One company cited corrosion problems with fluorinated material as a difficulty. Iodine and bromine can present a problem because of the coloured plume. (Merchant incinerators have similar problems but usually have the advantage of very high efficiency gas cleaning, and the ability to blend different types of wastes).

Reasons for selecting or considering the SLF-to-cement kiln route are mainly economic, although the ability of the cement kiln chemistry to fix materials such as halogens was also noted by companies. One company cited a concern, however, with the urban setting of the nearest cement kiln and possible environmental concerns or perceptions.

The cost of merchant incineration varies with composition. If the fuel value of wastes with high calorific value, such as relatively large glycol ethers and methanol streams, are recognised then merchant incineration can be economically reasonable.

Landfill is not a usual disposal option for regulatory and technical reasons. However, one company did quote an example of an alkaline aqueous stream with ten percent methanol. This is sent to treatment and landfill rather than incineration because of its very low flash point. Another company is considering a solidification process for a largely anhydrous material that is polymerisable.

One form of on-site treatment of aqueous organic wastes is wet air oxidation to produce a stream treatable by normal means. None of the sites contacted employed this technique, however.

In most cases of solvent use, there is some recycle within the process and recovery either on-site or externally. A possible exception is in the production of pharmaceutical actives and products, when the chance of cross-contamination rules against re-use within the process. This does not necessarily prevent recovery by external recycling companies for lower grade applications, however.

Quantities of waste in this sector are large, related to production, because of low yields in many processes. However, it should be noted that some companies have achieved notable reductions by process and management techniques. Over a period of around five years, reductions in excess of 50 percent are quoted.

2.1.8 Manufacture of formulated products

Formulated products are those in which components are blended together, often with physical treatment such as grinding but with a minimum of chemical reaction. Examples of formulated products are coatings, cleaning products, cosmetics and agrochemicals. Organic compounds in formulated product include solvents, and functional materials such as film-forming agents or biocide actives.

Waste from formulation operations are typically a small percentage of production, and consist of:

- used solvent, some of which may be recyclable by external specialists
- waste reagents and products (includes off-specification and out of date materials)
- washings.

Waste reagents and product quantities are typically up to 100 tonnes per year from a plant, and other wastes – perhaps partly aqueous – up to around 500 tonnes per year. The waste is usually drummed for disposal.

The chemical composition reflects the constituents of the relevant products.

Pigments in coatings and inks are of particular relevance because many are metals or compounds of metals. In metal-effect pigments, such as in automobile finishes, the pigment consists of flakes of metal such as copper, copper/zinc, aluminium bronzes, zinc alloys, etc. Whiteners include titanium dioxide, often used as a lightener in printing inks, and zinc sulphide compounds. Coloured pigments include oxides of iron and chromium, iron/cyanide compounds, lead and zinc chromates, molybdates and bismuth compounds. Metal phosphates – zinc, chromium, aluminium, barium, etc – are commonly used as corrosion-resistant materials. Inorganic extenders such as calcium carbonate may also be present.

Organic pigments take many forms, such as phthalocyanines, quinacridone pigments, anthraquinone pigments and azo-compounds. Organo-metallic compounds are used in some applications, such as textile dyes.

The other generic chemical type of particular interest is biocides, because of their direct or long term effect or because of possible concerns relating to products of combustion on disposal. In practice there has been a significant shift away from chlorinated compounds with probable long term environmental effects such as DDT, aldrin and dieldrin, and lindane. Organophosphates, carbamates, and pyrethroids are other categories.

Agrochemicals may be carried in solvents, primarily aromatic and aliphatic hydrocarbons in comparable quantities in this sector. There is, however, a strong and continuing trend from solvent-based (emulsifable concentrate) formulations to newer types such as emulsions in water or suspension concentrates.

2.1.9 Use of solvent products

Solvents may evaporate in use, such as in coating systems, or be used in liquid form as in some forms of cleaning. Liquid residues may arise from both. Some major sources are described below.

Paint wastes

Paints are examples of products where the solvent evaporates. A traditional solvent-based paint may contain around 70 percent solvent by weight, though this is substantially reduced in modern formulations. Even water based coatings usually contain some solvent, usually lower than ten percent. Depending on the type of paint, the solvents are typically white spirit or aromatic hydrocarbons and oxygenates. The oxygenates include alcohols, ketones and esters. A mixture of solvents is often used in the formulation to provide the right rate of drying.

Another important constituent is pigment. While the pigment is intended to remain with the coating, some will be in any wastes, with possible trace presence of metal compounds, as noted above for the manufacture of formulated products.

Paint wastes can arise from the formulation operation, such as on grade changes. For applications, industrial coating operations include vehicle painting, wood coating (furniture), can coating and coil coating (for metal products such as white goods). Vehicle refinishing (resprays) is another large application. The wastes from these operations might arise on colour changes, such as in a car spray line, or the cleaning up of spills or paint that has missed its target. Operations in this type of industry may produce relatively clean solvent material of restricted solvent type and composition plus a dirtier stream with substantial non-solvent contaminants. The dirtier stream could typically be laden with pigments. Paint wastes are typically a few tonnes to 50 tonnes per year; they are usually drummed.

Printing wastes

There are several types of printing, with flexography, gravure (non-publication) and screen printing representing the largest users. The industry sectors are flexible packaging, decoration (such as wallpaper), and publications. As a sector, printing uses very much less solvent than paints and coatings (see Section 2.3). The solvents used in printing include alcohols (methanol to butanol), various hydrocarbons such as white spirit and toluene, and oxygenates such as MEK (methyl ethyl ketone) and ethyl acetate. Water based inks are increasingly used where technically possible.

Solvent used for cleaning or waste inks may be produced. Copper is cited as a characteristic contaminant, though other pigment components such as iron blue and phthalocyanine pigments could also be expected.

Adhesives

Industrial adhesives can take several forms, such as contact adhesives, polyurethanes or nitrile systems. Typical industrial applications include sticking on soles of shoes, furniture assembly, or production of tapes and labels. This sector is comparable to that of printing inks in quantities of solvent used. Solvents include toluene, hexane, esters, ketones and some chlorinated solvents. Water based adhesives are well established where technically feasible, and use glycol ethers or similar solvents.

Wastes from manufacture and industrial applications include cleaning wastes and contaminated adhesives. Chlorinated waste is reported by one SLF blender to be sent as a single stream. Wastes are typically sent for disposal in lots of a few (205 litre) drums at a time.

Surface cleaning

Surface cleaning primarily relates to the removal of contaminants from metal surfaces. This covers a number of industrial sectors, such as automotive, aerospace, precision engineering and electronics. The cleaning may be in the liquid phase or, more usually for smaller pieces, in the vapour phase with continuously condensed and reboiled solvent. Chlorinated hydrocarbons have been the predominant solvents used, mainly trichloroethylene and perchloroethylene. Ozone depleting compounds such as methyl chloroform (1,1,1-trichloroethane) and CFCs are not used, or should not be. Non-chlorinated solvents are also used, including white spirit and ketones, though fire risks require consideration.

Aqueous cleaning systems are widely employed, though not ideal for all applications, and are largely inorganic in nature.

When the organic solvents are heavily contaminated with soil, they are either distilled on site or sent to an external company. The solvent residues are typically sent to incineration. The residues may be contaminated with metals and soil components such as greases and dirt. These wastes are usually drummed.

Dry cleaning

Dry cleaning of textiles is performed largely with perchloroethylene as solvent, in facilities ranging from small retail shops to centralised plants. Recovery of the solvent is required for environmental and occupational health reasons. The dirt and fabric from the textiles builds up in the solvent until disposal is required. The residual material contains, typically, sodium monoleate detergent, dirt and a minor proportion of perchloroethylene. It is usually despatched in drum quantities for recovery.

If hydrocarbon dry cleaning solvents are used, the residue is incinerable.

Other solvent users

There are various other solvent using applications from which waste solvents or waste products can arise. They include:

- timber preservation, where wastes may contain creosote and other active biocides in, usually, a hydrocarbon solvent
- pipeline flushing, where methanol can be used resulting in occasional large volumes of waste methanol
- film coating for diverse end uses, such as masking film, drawing office film, and foil printers.

2.1.10 Waste treatment and disposal

There are two sources of relevance in the waste treatment and disposal sector.

- Solvent recyclers recover solvents –either mixed or as single solvents – in distillation processes. The still residues contain the contaminants present in the dirty solvent and quantities of the solvent itself. These residues form a significant feed source for SLF. Distillation can proceed to different depths of recovery, and this topic is addressed further in Section 3 of this report.

- Waste contractors perform a collection round service, Material supplied to an SLF blender or an incinerator may come from several sources, which makes it very difficult to identify the original wastes.

A further possible source of material for use in cement kilns is sludge from sewage treatment. This would be available in very large quantities. However, sewage sludge is taken as being outside the scope of SLF. The issues connected with its use are not those raised by the House of Commons Environment Committee.

2.1.11 Oil wastes

Oily wastes arise as sludges from tanks or from oil/water separators on process plants, as noted above. Another important waste source is used lubricating oil, the largest volume working fluid described at the beginning of this section. Although lube oil production accounts for under one percent of total crude oil processing, the used lube oil is the main form of waste petroleum product. Unlike fuels, where the product is substantially destroyed in use, around half of lube oil usage is potentially recoverable as waste oil. Information in this section is drawn largely from a recent report by the European oil industry association CONCAWE.

Lube oil markets fall into three categories: vehicles, industrial and marine. In terms of on-shore waste generation, the marine market can largely be ignored. The vehicle market is predominately for engine oils, split about evenly between passenger cars and heavy duty diesel engines. Transmission oils, gear oils and greases are also part of the vehicle market. An important factor in the efficiency of collection and proper disposal is the extent to which passenger car owners perform their own oil changes.

The industrial lube oil market includes process oils, which are consumed in use, hydraulic oils, metalworking oils, gear oil, compressor oil and others. More specialised applications often require synthetic compounds that are not necessarily only hydrocarbons, as noted in Section 2.1.2.

Contaminants in use lube oils arise from several sources. Traces of metals such as iron, chromium, nickel, aluminium and copper arise from wear of engine or bearings. Detergent and other additives contribute up to a few thousand parts per million of calcium, zinc or phosphorus. Sulphur, at 0.2-1.0 percent, arises from the base oil itself or from combustion products. Lead contamination, originating as it does from leaded gasoline, is likely to decline from 100-1 000 ppm. Similarly, chlorine content will be reduced with the declining use of chlorinated solvents and of leaded petrol, to which chlorinated compounds are added as lead scavengers. Polycyclic aromatic hydrocarbons arise from incomplete combustion of the fuel. Water, at five to ten percent, is a combustion product, and light hydrocarbons, also at five to ten percent, originate from fuels.

There are several disposal routes for collected lube oils, in addition to illegal dumping. They include:

- burning in space heaters, cement kilns or waste incinerators
- reclaiming of segregated oils of known composition by simple processing, and returning to the original use
- reprocessing for use as fuel: either mild reprocessing for use in road stone plants or fuel blending; or severe processing to produce good quality industrial fuels
- re-refining to a virgin base oil substitute, in which there are several types of process technology.

While lube oils and similar working fluids are not a main source of SLF in the UK, in Germany around one-third of collected lube oils are sent to cement kilns.

Waste lube oils and other working fluids usually arise in small quantities in a large number of facilities such as garages, machine shops, etc. Specialist waste contractors service this market in the UK.

2.2 Waste compositions

A selection of contaminant concentrations of wastes used in SLF is given in Table 2.2. The data include information given in confidence by SLF blenders, and merchant incinerator companies. Information is presented as available. Full analyses are not essential for waste disposal companies, nor required for consignment notes, In particular, the absence of data on metals in the table does not necessarily imply an absence of metals.

Table 2.2 Typical compositions of waste available for SLF

Source type	Waste type	Examples of Organic Compounds	LHV	Halogens	Sulphur	Ash	Metals	
			(MJ/kg)	*(%)*	*(%)*	*(%)*	*(ppm)*	
Automobile manufacture and other coating	Paint wastes	Aromatic hydrocarbons, butyl acetate, butanols	29.0	Cl <0.1 Br <0.01		1.0	Ba 6600	
	Paint wastes (aqueous)	MEK, MIBK	2.0	Cl 0.2 F 0.1	-	9.8		
	Thinner waste	Toluene, xylenes, acetone, ethylbenzene	23-33	Cl 0.1-0.25	0-0.03	0.1-0.4		
Printing etc.	Printing wastes	MEK, ethanol, ethers, esters	20-28	Cl 0.1	-	0.1-4.5	Cu<1000	
	Ink Cleaner (water-based)	Hydrocarbons	3.0	Cl 0.2	0.1	0.6		
	Cleaning residues	Alkylbenzenes, acrylates, ethers	31.0	Cl 0.2	0.1	0.7		
	Press cleaning wastes	Hydrocarbons	14.0	Cl <0.1		0.5		
	Fixer and developer	Hydrocarbons	4.0	Cl 0.2 F 0.1 Br 0.2	3.7	5.8		
	Photo-resist wastes	Halogenated solvents	0-23	Cl 0.1-0.7 Br 0.1	0.1-0.3	0.1-2.8		
Furniture etc	Paint wastes; spray-booth wastes	Ethyl acetate, ethanol, butanols, butyl acetate, toluene, xylenes	20-32	Cl 0.1-0.6	0-0.1	0.4-2.8	Ba 57	Mo 320
	Adhesive waste	Methylene chloride, acetone	9.0	Cl 69	-	1.9		
	Adhesive waste (aqueous)	Hydrocarbons	0.0	Cl 0.1	0.1	3.1		
Dry cleaning	Solvent residues	Perchloroethylene, sodium monoleate	10.0	Cl 10.0		10.0		
Manufacturing (fabrication, engineering)	Surface cleaning	Trichloroethylene	6-12	Cl 15-50		0-0.5		
	Cleaning washes	Trichloroethylene	0	Cl 1.0-10 F 0-0.2	0-0.1			
	Printing waste	Methyl chloroform, trimethyl benzene, cyclohexanone, common solvents	28	Cl 4.8 F 1.4		3.1		
	Cutting oil	Hydrocarbons etc. (small quantity)	0	Cl 0.4	0.1	1.3		
	Welding oil residues	Hydrocarbons	41		0.1	0.1		
Electronics	Waste solvents	Toluene, other hydrocarbons	24-26	Cl 0.02-0.05 F 0-0.04	0.1			
	Waste solvent (chlorinated)	MEK, glycol ethers, dichlorobenzene	25	Cl 2.2	0.8	0.1		
	Still residues	Higher hydrocarbons	42	Cl 0.8	1.0			

Table 2.2 Typical compositions of waste available for SLF (Cont.)

Source type	Waste type	Examples of Organic Compounds	LHV *(MJ/kg)*	Halogens *(%)*	Sulphur *(%)*	Ash *(%)*	Metals *(ppm)*	
Timber treatment	Spent wood preservative	Chlorinated phenols, metal salts of organic acids	44	Cl 0.7	0.1	1.8	Zn, Cu	
	Preservative washings	Chlorinated phenols, metal salts of organic acids, inorganic metal salts	0-8	Cl 0.1-0.2	0.1	0.1	Cu,Cr, As,Zn	
Agrochemical use	Washings	Chlorinated biocide	4	Cl 0.1	0.1	0.2		
Various solvent using industries	Mixed solvents (low halogen)	Various	1-42	Cl 0-1.0 Br 0-0.6 I 0.0.6	0-1.3	0.1-11.0		
	Mixed solvents (medium halogen)	Various	4-35	Cl 1.0-10 Br 0-1.6 I 0-3.0				
	Mixed solvents (high halogen)	Various	16-34	Cl 10-50 Br 0-13				
Solvent recycling	Residues	Heavy hydrocarbons etc	20-42	Cl 0.02-1.5 F 0-0.62 Br 0-0.2	0-0.6	0.1-4.0	Hg <20 Tl <40 Cd <10 As <10 Co <50 Cr <250 Fe <500	Ni <100 Pb <40 Sb <15 Mn <50 V <20 Cu <100 Ti <1200
	Distillate	Hydrocarbons (trace)	0	Cl 0.02 F 0.04	0.02			
Refining and Petrochemicals	Polymerised residues (refinery)	High MW hydrocarbons	39	Cl 0.01	0.18			
	Spent reagent residues (refinery)	DEA, acetates	26	Cl 0.04 F 0.01	0.19			
	Waste tars (petrochemicals)	Aromatic and naphthenic compounds	39		0.1	0.1		
	High CV side stream	Oxygenated compounds	32				Cr 200	Bo
	Byproduct stream	Glycols and amines	13	Cl 0.04	0.02			
	Caustic wash		4-8	Cl 2-4	0.3-1.1	4-12		
	Tank washings	Hydrocarbons	0	Cl 0.1	0.1	0.4		
	Sludges	Various	3-7	Cl 0-2.5	1.3	2-4		
Resin manufacture	Methanol/water	Methanol	18.5	Cl 0.1	-	0.1		
Fine chemical production	Pesticide waste	Dimethyl formamide, toluene, methanol, chlorinated compounds	25	Cl 2.0		0.1		
	Dyestuff intermediates	Azo compounds	26	Cl 0.8 F 0.03	0.01			
	Distillation residues	Cresolic and phenolic compounds	17		2.8	4.4		
	Distillation residues	Hydrocarbons	41	Cl 0.54 F 0.05	0.5			
	Mixed solvent residues	Various	36	Cl 0.1 F 0.01	0.07		Co 40 Cr 650 Cu 18 Fe 823	Mn 11 Pb 3700 Sb 250 Ti 7500 V 40
	Solvent residues	Isopropanol, glycol ethers	28	Cl 0.1	0.1			
	Waste solvents (mixed)	Various	21-36	Up to Cl 0.11 F 0.08 Br 1.3	0.07		Fe 400	Sn 220

Table 2.2 Typical compositions of waste available for SLF (Cont.)

Source type	Waste type	Examples of Organic Compounds	LHV (MJ/kg)	Halogens (%)	Sulphur (%)	Ash (%)	Metals (ppm)
Fine chemicals production	Chlorinated solvents	Methylene chloride, chloroform	17-25	Cl 2.0-4.0 F to 0.7	0-0.8	0.1	
	Chlorinated solvents (concentrated)	Methylene chloride	12	Cl 47.0	0.02		
	Brominated solvents waste	Bromochloropropane etc	4-14	Cl 0.1-17 Br 4-40 I 0-0.5	0-1	0.1-4.0	
	Brominated solvents residues	Bromochloropropane etc	15-17	Cl 2-21 Br 13-32	0.1	0.1	
	Waste solvent	Tetrahydrofuran	25	Cl 1.4 F 0.03	0.1		
	Waste solvent	DMF (dimthyl formamide) with iodine	21	Cl 0.7 I 3.4	0.1	0.1	
	Waste solvent	Isopropanol, DMF	26	Cl 0.1 F 0.01	0.2		
	Waste solvent	Chlorotoluene	13-35	Cl 3-30	1.0-7.0	0.1 -2.0	
	By-product		27	Cl 0.15 F 0.06	0.3		
	By-products, wastes	Halogenated aniline compounds, chloromethanes	25	Cl 2.0 F 1.0 Br 0.2			
	Process/solvent wastes	Acetic acid	14-25	Cl 0.1-1.5 Br 0.1 I 0.1-1.1	0-1.4	0.1-1.0	
	Mother liquor	Hydrocarbon solvent	39	Cl 1.4 F 0.2			
	Waste tars		19-37	Cl 2.0-20.0	0.1	0.1	
Coatings manufacture	Solvent and paint wastes	Toluene, ketones	33	Cl 0.2	0.1	12	Al and Fe
	Coating wastes	Alkylbenzenes, pyrrolidones, cresols	34	Cl 0.1 F <0.01		0.1	
Food	Preservative		32	Cl 0.1	-	0.1	
Cosmetics	Waste product	Ethanol	20	Cl 0.1	-	1.1	
Transport etc.	Waste fuels/oils	Hydrocarbons	42	Cl 0-2	0-1	0-1.0	
Waste service industry	Mixed waste	Various	0-40	Cl 0.1 F 0.02	0-1.0	0-21.0	
	Plant washings	Various	0	Cl 0.05 F 0.02	0-2.0		

A number of observations may be made:

- Several of the wastes have a low or even negligible energy content. They are substantially water, with some contamination. This tends to contradict the suggestion that SLF includes only high energy content wastes, thus depriving merchant incinerators of important feedstock. However, it does raise the question as to whether contaminated water should be sent to cement kilns. Dilute wastes are one of the cases considered in the Life Cycle Assessment.

- Chlorine, while negligible in many wastes, is present in high concentrations in some. These wastes are predominantly "single solvent" types, such as methylene chloride or trichloroethylene. Apart from the issue of whether such streams are recyclable, there are particular environmental questions associated with chlorine compounds. High concentrations of other halogens are also noted with some wastes.

- Sulphur content is, on the whole, quite low compared to, for example, heavy fuel oil.

- The ash content can be reasonably high but is lower than that from many types of coal.

- The metal content is very variable. Lack of data on the table does not necessarily imply absence in the waste. Residues from solvent recycling, and wastes from coating operations, are potentially significant sources. One of the key questions for the LCA is therefore what happens to metals in SLF in cement kilns or other disposal routes.

- Table 2.2 includes the chemical species of the main organic components, when known or deducible. Examples of other organic compounds are listed in Table 2.3.

Table 2.3 Further examples of organic compounds in incinerable waste

Hydrocarbons and phenols	Other, including oxygenates	Chlorinated
Hydrocarbon cuts (white spirits etc)	Formic acid	Ethylene dichloride
Benzene	Oxalic acid	Chlorinated phenols
Hexane	Isocyanates	Waste with PCBs
Octane	Organic peroxides	
Cyclohexene	Epoxy resins	
Kerosene	Cyanides	
Bitumen, asphalt	Amines	
Vegetable oils	Amides	
	Nitriles	
	Organophosphorus compounds	
	Organosulphur compounds	

The composition data are used to frame the cases analysed in the Life Cycle Assessment in Section 3. This analysis is structured around waste characteristics, not industrial sources.

2.3 Quantities of waste streams

One of the objectives of the study is to identify the quantities of wastes arising that could be candidates for SLF. Estimation in the area is not simple; some methodological approaches are noted below.

Table 2.4 shows the number of organic waste consignments in selected categories for a single year, as reported in the Environment Agency's database. The database is being established and is known to be incomplete. The number of consignments, of over 114 000, is therefore an underestimate. Data on the number of operating units (usually plants) in the UK are shown in Table 2.5.

Table 2.4 Organic waste arisings: Number of consignments in selected categories (12 months 1996/7 - partial)

Region	Basic Organics	Fine Chemicals	Pesticides	Pharma-ceutical	Paint	Oil Wastes	Total
Anglian	947	243	389	296	1 921	6 442	12 550
Welsh	296	425	5	48	310	2 758	5 113
Thames	268	86	92	668	2 252	4 989	10 109
Southern	493	126	98	1 046	310	2 836	6 104
South-West	198	301	23	321	314	2 609	5 100
North-West	1 736	1 915	238	1 254	1 271	6 026	16 568
North-East	4 677	2 997	3 833	1 097	6 085	13 543	41 744
Midlands	995	473	13	309	2 267	6 110	14 940
Scotland West	44	28	11	28	55	220	550
Scotland North	12	7	3	7	14	58	144
Scotland East	92	57	23	57	115	459	1 147
TOTAL	**9 757**	**6 658**	**4 728**	**5 131**	**14 914**	**46 049**	**114 069**

Table 2.5 Information on number of UK operating units in selected types of industry

Schedule A authorisations:	783	Oil refining, petrochemicals, organics, pesticides, pharma (Not halogen processes, fertilisers, diisocynates)
Number of UK Business Units		
Chemicals	2 800	
Surface cleaning	4 600	
Printing	20 740	
Furniture	834	
Adhesives	1 025	Manufacturers and footwear producers
Other solvent users	930	Other coating (not vehicle respray) rubber, timber preservation etc

From the large number of wastes and possible producers, it is clear that estimation of the total waste arisings from a statistical sample would be very difficult. The quantity per consignment and per producer varies widely.

The ideal source of information, of course, is a database in which all UK arisings are reported by type. In fact, the Environment Agency is establishing such a centralised database as noted above, but the system was not completely operational at the time this report was compiled. The Environment Agency database is, with these limitations, a valuable source of information.

A similar source could be a national waste inventory reported by another country. The Toxic Release Inventory of the United States is not very helpful in this respect as it covers only specified pollutants and is aggregated by site. Germany provides a more promising basis, with special waste quantities broken down by industry and by waste type. Conversion factors are needed to relate German quantities to UK quantities. These can be only approximate, but, once more, the estimates are useful indications.

These estimation methods are basically "bottom-up", derived from reports of waste quantities. The other approach is "top-down".

A top-down approach could involve obtaining data on consumption or production of particular materials, from quoted statistics or by other forms of estimation. The quantities going to various destinations, such as atmospheric emissions or liquid organic wastes, are then derived using available correlations. Top-down methods tend to be more useful in estimating total organic content rather than total waste quantities. The water or solids content may vary very widely, for example.

None of these methods is ideal, and the definition of waste types is not consistent. For these reasons, a combination of techniques is used in this report, in the knowledge that the results will not match exactly. A degree of comfort may be achieved in some instances, or the uncertainties highlighted in others.

A review of estimates of waste quantities by different methods is presented below, under the following headings:

- Environment Agency Database
- Germany waste statistics
- Chemical industry estimates
- Solvent waste
- Waste oil
- Summary of estimates of waste quantities.

2.3.1 Environment Agency database

The records in the Environment Agency database are split down by the categories identified in the European Waste Catalogue. As noted above, the information drawn from the database is incomplete and the areas of incompleteness can not be identified.

Chem Systems used information for a recent 12 months supplied by the Environment Agency in an Access database. Date were extracted for all categories that are, in general, potential candidates for SLF. This amounts to several tens of thousands of consignments. The data were converted to tonnes from the various units quoted: cubic metres, cubic yards, gallons, kilograms and litres. Some very large consignments were omitted where it was likely that units had been misquoted or were for very dilute wastes.

The compiled data are summarised in Table 2.6. It is difficult to break down the data to identify exactly which wastes would be suitable for SLF. Compositions may vary even within the sub-categories not shown in the table. The category of "other" wastes under each heading is usually significant.

Of the total 1.8 million tonnes shown in Table 2.6, roughly one half consists of various forms of waste oil or other vehicle liquids. The remainder includes solvent-type wastes and process wastes such as distillation residues.

Table 2.6 Partial estimate of arisings of selected wastes, UK, 1996/7 (thousand tonnes per year)

Waste Code	Source of waste	Midlands	North-East	North-West	Others	Total
020105	Agrochemical wastes (farming)	0	1	0	12	**13**
020303	Food processing (solvent extraction)	0	0	0	0	**0**
020700	Beverage production	0	0	0	0	**0**
030200	Wood preservatives (organic)	0	0	0	0	**1**
030305	Deinking sludges	0	0	0	0	**0**
040103	Leather: degreasing	0	0	0	0	**0**
040200	Textiles: dressing, pigments etc	0	0	0	0	**1**
050800	Oil regeneration (aqueous)	2	0	0	1	**3**
070100	MFSU of basic organic chemicals	56	82	29	34	**201**
070200	MFSU of plastics, etc	7	0	20	6	**34**
070300	MSFU of organic dyes and pigments	0	4	3	1	**8**
070400	MSFU of organic pesticides	0	74	3	14	**92**
070500	MSFU of pharmaceuticals	2	15	18	33	**69**
070600	MFSU of soaps, detergents etc	1	7	12	3	**23**
070700	MSFU of fine chemicals etc	9	48	33	25	**114**
080100	MSFU of paint and varnish	28	27	15	27	**97**
080300	MFSU of printing inks	5	16	6	8	**35**
080400	MFSU of adhesives etc	2	2	4	4	**11**
090100	Photographic industry	0	0	0	0	**0**
120100	Machining etc	74	83	10	19	**186**
120300	Steam degreasing etc	3	1	0	2	**6**
130100	Hydraulic oils and brake fluids	4	14	52	7	**76**
130200	Engine, gear & lubricating oils	11	184	6	31	**231**
130300	Insulating and heat transmission oils etc	1	2	0	2	**5**
130400	Bilge oils	2	8	2	17	**28**
130500	Oil/water separator	51	59	14	121	**245**
130600	Other oil waste	43	185	9	60	**297**
140100	Metal degreasing etc	5	6	1	5	**17**
140200	Textile cleaning etc	0	0	0	0	**1**
140300	Electronics industry	0	1	1	1	**3**
140400	Coolants, foam/aerosol propellants	0	0	0	0	**1**
140500	Solvent and coolant recovery residues	3	11	6	17	**37**
	Total	**309**	**831**	**246**	**451**	**1 837**

MFSU = manufacture, formulation, supply and use

WARNING: Data are indicative only and are known to be incomplete

2.3.2 German waste statistics

The German national statistical organisation, Statistisches Bundesamt, compiles regular inventories of special waste and their destinations. The latest available data are for 1993. The data are split into waste categories that do not match those of the European Waste Catalogue exactly.

Chem Systems has extracted data for the waste categories that appear most relevant to SLF. These are summarised on Table 2.7. The selection is more focused than was feasible for the Environment Agency data. The statistics for both 1990 and 1993 cover unified Germany. With some exceptions, there is a systematic drop in waste quantities between 1990 and 1993. Data for distillation residues show a switch from halogenated solvents, but this trend is not apparent from solvent waste data.

Quantities for the UK in 1997 have been estimated from those for Germany in 1993 using simple conversion factors. The factors are approximate and are based on ratios between the countries of population, GDP, the vehicle fleet and the added value of the chemical industry as appropriate. These estimates are compared with other sources in the sub-sections following.

Table 2.7 Selected organic wastes from German industry and hospitals

Category	Germany Quantity 1990 *(tonnes)*	Germany Quantity 1993 *(tonnes)*	Conversion Factor	UK Quantity (1997) *(tonnes)*
Waste oils, fuels etc	491 995	441 343	0.70	308 940
Oily water	40 152	69 110	0.60	41 466
Oil etc with PCB	41 778	92 522	0.60	55 513
Phenol water	318 271	41 931	0.50	20 966
Organic acids	4 842	4 611	0.45	2 075
Chlorinated materials	15 447	14 711	0.60	8 827
Methanol/alcohols	59 491	43 488	0.50	21 744
Other oxygenates	33 901	32 287	0.50	16 144
Amines	15 253	15 830	0.50	7 915
BTX	34 343	55 192	0.50	27 596
Surfactants etc	5 624	12 686	0.50	6 343
Distillation residues (halo solvent)	49 969	24 732	0.60	14 839
Distillation residues (non-halo solvent)	45 119	74 266	0.50	37 133
Distillation residues	59 481	47 699	0.50	23 850
Solvents (non-halo)	223 341	212 706	0.60	127 624
Solvent wash (non-halo)	36 310	34 581	0.60	20 749
Solvent sludge (non-halo)	5 434	5 175	0.60	3 105
Solvents (halo)	106 714	101 632	0.50	50 816
Solvent wash (halo)	16 703	15 908	0.50	7 954
Solvent sludge (halo)	7 353	7 003	0.50	3 502
Adhesive wastes	17 439	12 781	0.60	7 669
Coating sludges etc	220 934	179 689	0.60	107 813
Printing wastes	15 033	11 210	0.60	6 726
Organic pigments etc	13 003	7 507	0.40	3 003
Lab chemicals	6 980	4 524	0.50	2 262
Various petrochem sludges	7 281	4 779	0.50	2 390
Plastic & rubber sludge	34 029	117 216	0.40	46 886
Tank Sludges	33 897	26 268	0.50	13 134
Cutting wastes	65 766	46 176	0.50	23 088
WWTP sludge	1 865 537	589 996	0.50	294 998
Total	**3 891 420**	**2 347 559**		**1 315 067**

2.3.3 Chemical industry estimates

SLF-type wastes from the chemical industry include both solvent wastes and others described in Section 2.1. The solvent wastes from the chemical industry arise primarily from fine chemical producers, including those manufacturing pharmaceutical active ingredients.

Data aggregated across the sector are not available from producer organisations sources such as the Chemical Industries Association and the Association of the British Pharmaceutical Industry.

Estimates for total incinerable organic wastes from the chemical industry, including fine chemicals and pharmaceuticals, are compared in Table 2.8. The data for the German chemical industry are broken out from the national statistics shown in Table 2.6. Solvent wastes accounts for just over half the total and distillation residues a further 20 percent. Tank sludges are included in the estimates derived from German data, but wastewater treatment sludge is not.

The third source, in addition to Environment Agency and German data, is a model developed by Chem Systems. This was produced in a confidential assignment in order to estimate incinerable waste arisings from the UK chemical industry. Around 330 chemical and fine chemical sites are modelled, covering 14 categories of plant. The quantity of wastes estimated for each plant is a very broad judgement. The individual factors used were supported by interviews with around 50 companies. For this report on SLF, waste factors were checked by a review of IPC documentation for around 40 plants and contact with selected companies.

Table 2.8 Estimates of incinerable wastes from the UK chemical industry (1997)

Source	**Basis**	**Estimate** *(thousand tonnes per year)*
Environment Agency database	MFSU[(1)] of basic organic chemicals, fine chemicals and pharmaceutical (partial reporting)	384
Germany national statistics	Converted from selected data for 1993 to UK data from 1997	375
Chem Systems model	Database of UK plants with very approximate estimate of arisings	395

Note (1) MFSU = Manufacture, formulation, supply and use.

The data on Table 2.8 show reasonable agreement. To some extent, this gives a misleading impression of accuracy as the definitions of wastes and sources are not completely identical. The Environment Agency data, for example, is based on manufacturer through to use and the report is not complete. However, a degree of comfort can be drawn that the estimates do not differ by orders-of-magnitude.

2.3.4 Solvent wastes

Estimation of the quantity of solvent wastes is one area in which top-down analysis may possibly be used. In many solvent applications, the solvent is meant to evaporate, and it will be completely lost in domestic uses such as aerosols. For industrial uses, such as coating, the solvent that evaporates may be emitted directly to atmosphere, destroyed by incineration, or recovered by adsorption or other techniques. In cases where the solvent is recovered and reused, as with metal degreasing (vapour systems) or dry cleaning, there is often liquid waste containing solvent and contaminants. Wash solvent waste is also produced in many applications.

Table 2.9 shows an appropriate estimate of solvent use in the UK in 1997. This is not the result of a market survey for this study, but an update of work performed earlier by Chem Systems in a confidential assignment. The quantities shown include recycled solvent, both single solvent and mixed. Several of the solvent compounds can be used for chemical synthesis purposes. This applies to toluene, xylenes, acetone (DMK) and certain chlorinated hydrocarbons for example. Where possible, the non-solvent uses are omitted from the quantities, but it is not always feasible to identify different end-uses within a sector. The "other" row on the table includes formulated domestic products such as cosmetics and cleaning or stripping agents.

Table 2.9 Solvent use indicative estimates, UK, 1997

Sector	Hydrocarbon	Oxygenated	Chlorinated	Mixed	Total solvent *ktpa*
Paints and varnishes	46%	48%	0%	6%	364
Printing ink	58%	37%	0%	6%	57
Adhesives	27%	59%	8%	5%	51
Pharmaceutical/fine chemical	4%	76%	16%	4%	95
Agrochemicals	95%	2%	0%	4%	12
Surface cleaning	0%	0%	94%	6%	59
Other	48%	43%	4%	5%	294
Total solvent	**40%**	**46%**	**9%**	**5%**	**932**

Basis: Chem Systems data for European market, updated from 1995, UK split out approximately

From these data, tentative estimates are presented in Table 2.10 of solvent waste quantities. The table shows solvent wastes sent to recycling operations, recycling residues which pass to other disposal operations, and other sources of solvent wastes. The estimates of other sources and the assumed average solvent content are order-of-magnitude judgements.

Table 2.10 Solvent waste estimates, UK, 1997

	Solvent content *ktpa*	Total waste *ktpa*
Waste solvents to recycling	145	170
Recovered solvent	110	
Residues from solvent recycling	35	60
Other solvent wastes to disposal	40	80
Total solvent wastes	185	250
Net solvent wastes (1)	75	140

Data on recycling derived from data by CORA and IAL consultants, 1994

(1) After recycling

These data indicated that a significant proportion – over half – of the solvent in waste streams is recovered.

2.3.5 Waste oils

Oily wastes of various sorts are one of the largest categories identified from the Environment Agency's database. Some types of oil waste, such as from oil/water separators, or "other oil waste" are difficult to estimate. One oil waste that has been quantified is that of waste lubricants.

The data in Table 2.11 are drawn from a recent (1996) report by the oil industry organisation CONCAWE. The quantities are for 1993. Industry sources estimate that the waste oil quantity rose by around 15 percent between 1993 and 1997, reflecting slow annual growth and further improvement in collection efficiency.

Table 2.11 Collection and disposal of used oil by the UK, 1993 (1)

Collection		Disposal	
	(thousand tonnes)		*(thousand tonnes)*
Automotive	175.3	Waste incinerators	5.0
Industrial	23.4	Garage heaters	40.0
Total	**198.7**	Reprocessing	123.7
		Reclaiming	30.0
		Total	**198.7**

(1) Source: Collection and Disposal of Used Lubricating Oil, CONCAWE, November 1996

These data therefore are of the same order-of-magnitude as those in Table 2.5 for engine, gear and lubricating oils. The efficiency of collection from industrial sources in Germany is, according to the CONCAWE estimates, rather higher than in the UK. This partly explains why the estimate calculated from German data, in Table 2.6, is rather high.

2.3.6 Summary of waste quantities

There is insufficient information available to permit the quantities of candidate wastes for SLF to be estimated with a high degree of confidence. The data in Table 2.12 are tentative estimates based on the sources presented in this section.

Table 2.12 Summary estimate of quantities of selected organic wastes in the UK, 1997

Waste type	Quantity *(000 tpa)*	Comment
Chemical industry: non-solvent	250 - 350	Includes on-site residues
Chemical industry: solvent wastes	60 - 90	
Paints, coatings	90 - 130	Part to recyclers
Surface cleaning etc	25 - 30	Part to recyclers
Other solvent users	35 - 55	Part to recyclers
Recycling residues	50 - 70	
Lube oils etc	220 - 250	Other disposal routes
Other oily wastes	500 - 600	Other disposal routes
Net Total (2)	**1 100 -1 350**	
Gross Total (1)	**1 185 -1 505**	

(1) All wastes but not recycling residues

(2) Allowing for solvent wastes sent to recyclers : only the residue added in

The largest volume wastes, of lube oils and other oily wastes, do not appear to be used in either SLF or merchant incinerators to any great extent. Economics is the main driver for this in the case of lubes. The "other oily waste" category includes oil/water separator sludge which would normally be expected to pass through some oil recovery system.

Without these components, the total waste in the selected categories amounts to between 380 000 and 500 000 tonnes of waste per year.

2.3.7 Demand for SLF

The total possible demand for SLF in UK cement kilns depends upon the extent to which fuel substitution is permitted by the Environment Agency. Under the terms of the EC directive on hazardous waste incineration (94/67/EC), the hazardous waste incinerator limits would apply if energy from hazardous waste is 40 percent or more of the total energy generation. This is a practical limit to further substitution.

It is also possible for cement kilns to burn other wastes, such as tyres and plastics. Some plants either burn or are considering burning material of this type, so would not necessarily be users of SLF.

Table 2.13 shows the maximum quantity of SLF that could be burnt in UK cement kilns in various circumstances. Allowance has been made for the processes in operation at each site, and SLF is taken to have a calorific value of 25 MJ/kg.

Table 2.13 Maximum SLF consumption in cement kilns

Cement kilns	Substitution *(%)*	SLF use *(000 tpa)*
Authorised/trials (October 1997)[1]	Various	215
All except those with tyre/plastic burning interest	25	340
All except those with tyre/plastic burning interest	40	540
All kilns	40	840

[1] Ketton is included in this.

The estimates shown in Table 2.13 are maxima and actual consumptions would be significantly less. Nonetheless, a tentative conclusion may be drawn that the potential demand for SLF in cement kilns could be very significant in relation to the total arisings of suitable wastes. It might imply the use of lube oil in cement kilns, as in Germany, or some of the general "oily wastes" reported in the Environment Agency database. However, this conclusion needs to be checked when the Environment Agency's system to compile waste data is fully established.

3. Life Cycle Assessment (LCA)

3.1 Approach

3.1.1 Introduction to LCA

The report on the environmental Life Cycle Assessment is presented in the following parts:

- **Section 3.1:** the methodology underlying the analysis
- **Section 3.2:** the specifics of the systems studied in the review of SLF
- **Section 3.3:** the Life Cycle Inventory data and the conclusions to be drawn from them
- **Section 3.4:** consideration of environmental impact issues
- **Section 3.5:** conclusions of the LCA.

Life Cycle Assessment (LCA) is an analytical technique used to evaluate the environmental burdens from systems associated with a product, process, or activity. The environmental burdens include the consumption of natural resources and the releases of wastes to the environment. The assessment includes the entire "life cycle" system encompassing extraction and processing of materials, manufacturing steps, transport, use of a product, recycling and final disposal. Where partial life cycles are considered, the term "ecoprofile" is often used. This convention is not adopted to avoid confusing the reader.

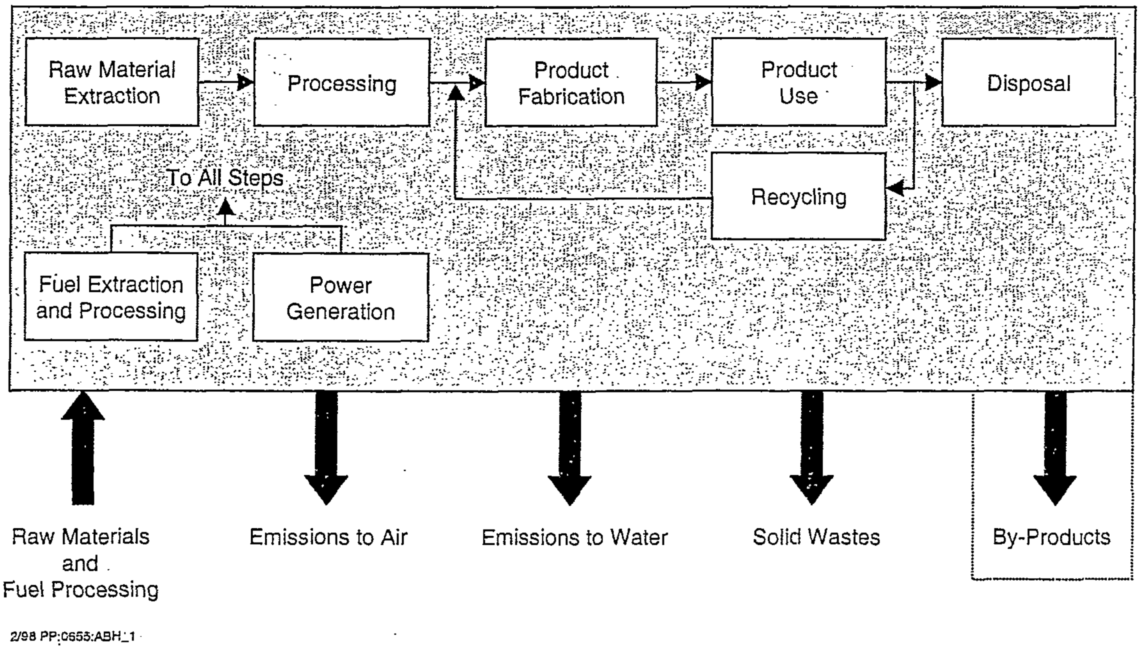

Figure 3.1 Typical LCA system

The total environmental burdens include those arising from the generation of power and the use of transport, as Figure 3.1 indicates.

Life Cycle Assessment proceeds in several stages, usually categorised as follows:

- goal definition and scoping
- Life Cycle Inventory (LCI), in which the data on consumptions of resources, emissions and other relevant factors are collected and calculated
- Impact Assessment, where the LCI data are related in some way to actual environmental impacts
- utilisation, such as an assessment of the possibilities for impact improvement.

The analytical framework for the study of SLF is reviewed in Section 3.1.2 below. Notes on the methodology employed are given in Section 3.1.3; non-specialist readers may care to skip this part.

3.1.2 Analytical framework

All LCA is ultimately used for comparisons, whether between products, policy options, or improvement possibilities.

An essential part of a meaningful analysis is a definition of the appropriate comparisons. The study into the use of SLF in cement kilns has features that are different to many LCA studies relating to product life cycles or recycling options, for example. The basic principles used in the SLF study are therefore outlined here.

(a) Basic question

The question to be answered is, for different types of waste, is it environmentally preferable to direct waste to:

- SLF blenders and then a cement kiln, where it displaces coal or petcoke as fuel
- an alternative form of disposal, primarily high temperature incineration
- recovery of solvent values for recycling, displacing the need for production of new solvent?

This question is not the same as whether a kiln or incinerator burning SLF operates within limits set by regulators, and the data requirements are different.

(b) Options compared

The disposal options compared in the study are:

- high temperature incinerators

- use as SLF in cement kilns
- recycling of solvent value.

In each case, the wastes considered are those arising after all on-site recovery or processing has occurred.

(c) Options excluded

The option of landfill of the SLF-type waste is not included in the analysis. There is a strong trend to exclude organic wastes from landfill and this is expected to be further formalised in the EU Landfill Directive. The conventional terms of reference for LCAs assume that all operations comply with the law or other regulatory standards. It is beyond the remit of a study on SLF to reconsider the technical basis of landfill exclusion criteria that have been extensively analysed by others in international fora. In essence, the disposal options considered are those judged to be permissible in the current and coming regulatory environment.

It should also be noted that there are practical difficulties in including landfill in the LCA. While the fate of components of putrescible waste can be modelled, the data on chemical organic wastes are not clear. For example, there is evidence that some vinyl chloride may be emitted as a result of chlorinated solvents in landfill, but the research data are not available to define to what extent this occurs. The final outcome will also depend upon the total mixture in the landfill. There is a difference too in the nature of environmental problems associated with landfill and other disposal routes. With landfill, the emphasis is on containment over a long period, with possible risks of failure to contain or risks of fire hazards. With a disposal route such as incineration, much of the environmental burden occurs in a very short period. While LCA methodology does provide some structure for considering trade-offs between different types of impacts, it is difficult to avoid a mixed message in these circumstances.

Another option for disposal of organic wastes is that of discharge to sewer or directly to surface water as aqueous effluent. This is excluded from the LCA for the same two reasons as for landfill: this would not normally be a permissible disposal route and – of secondary importance – there are practical difficulties in modelling it.

Chem Systems is not aware of waste streams that could be plausibly blended into SCF instead of being sent to sewer. As with landfill, if disposal to sewer is not permitted by regulators, it should not be considered as a disposal route in the LCA.

The environmental impact of discharge to water – whether or not via a treatment system – will be heavily dependent on the chemical species present. Degradability (aerobic and anaerobic), sorption characteristics, acute toxicity, and long term effects including bio-accumulation are all relevant. As the European Commission has shown in the work on ecolabelling of laundry detergents, it is an enormous undertaking to compile these data even for a limited rate of compounds. The actual environmental consequences depend also on the state of the receiving watercourse and the nature of the aquatic ecosystem.

It would therefore be very difficult to incorporate disposal to sewer or watercourse in the LCA in a meaningful manner.

The focus on disposal routes other than landfill and discharge to sewer is consistent with the concerns expressed by the House of Commons Environment Committee.

(d) System configuration

The systems to be compared are shown in simplified form on Figure 3.2. The selection of systems may appear strange, but it must be remembered that it is not the absolute impacts that are of interest, but the differences between options. For example, all the systems include a cement kiln even when SLF is not sent to this destination. This is to permit the calculation of the difference between a cement kiln using conventional fuel and one using SLF.

The first system – the incineration option – includes the high temperature incineration of the SLF.type waste in a merchant incinerator. It is assumed that this is an incremental load on an incinerator that is already running with a balanced burn menu, and does not displace anything else. No allowance is made for the possibility that more low-energy wastes (non-SLF) may be economically incinerated if the SLF waste has a high energy content and acts as a support fuel. That would be an economic, not an environmental, argument. If the low-energy non-SLF wastes are suitable for incineration then they should most probably be excluded in any case from other disposal routes such as landfill. This is a broader issue of regulation and motivation than is appropriate for this report. However, one case is considered where a substantially hydrocarbon SLF waste is used to displace fuel in the incinerator. This case therefore models an incinerator with an energy deficit because it is burning other low energy (non-SLF) wastes.

System I also includes the cement kiln, using traditional non-SLF fuels: coal and petcoke.

The second system is when the waste is used as SLF in cement kilns. In this case, the incinerator is omitted because, in System I, SLF is taken as an incremental incinerator load rather than a substitute for other materials.

It should be noted that petcoke could be considered an unavoidable product from refineries of certain configurations. In other words, the petcoke would be burnt somewhere if not in a cement kiln. This factor is not taken into account in System II. The petcoke might be burnt on some other facility, such as a furnace with flue gas desulphurisation, where impacts would be different. In addition, petcoke is not an essential product of refineries; refinery configurations could be altered in the long term so that petcoke is not made. Only one UK refinery currently produces petcoke. These arguments do not apply to coal. If it is not bought, it is not mined.

System III shows the SLF-type waste passing to a solvent recycling facility. In some instances, the SLF-type waste could be residues from solvent recycling, so that the question is one of deeper recovery on the recycling plant. However, the simplification is made that the choice is between recycling and not recycling. As the processing effort increases for higher recovery rates, this approach may understate the environmental burdens of the recycling operation. This is considered in the review of results.

System III also shows the displacement of the requirement to make new solvent, one of the main benefits of recycling. This shows up in the LCI as negative environmental burdens. In effect, this is an expression of the difference between making new solvent and not making it. The same answer could be achieved by including the production of new solvent in System I and II, and omitting it from System III. This latter form of presentation was rejected because it could mask comparison between cement kiln and incinerator routes. Finally, System III includes the cement kiln continuing to use coal and petcoke.

The target of the analysis is to find the difference between the environmental impacts of the three systems.

(e) Scope of systems

The interest in this LCA is in the use or disposal of SLF-type wastes by different routes. The incremental changes are of relevance rather than the total impacts of, for example, manufacturing cement. However, some appreciation of total processes is required before the incremental changes can be assessed. For example, the type of fuel or waste burnt will influence the need to grind solid fuels and therefore the power consumed.

Chem Systems has therefore reviewed information provided in confidence by operators to check whether such factors could be significant.

In general, however, the analysis is made on the basis of a factors relevant to a unit of SLF waste. Different waste compositions are considered in different comparisons.

A fuller description of system boundaries is given under the heading of Methodology below.

(f) Calculation methods

Where possible, LCAs should be based on real measured data that are directly applicable to the subject studied. Where processes have more than one output, the measured quantities are divided between outputs using various allocation techniques.

For the LCA on SLF disposal routes, important questions are those below.

- What is the destination (e.g. air, solid waste) of metals, halogens, sulphur, etc, entering incinerators, kilns or recycling plants?
- What is the impact of the pollutants in these different destinations? For example, will metals leach out of solids?
- What happens if low energy materials are fed to kilns or incinerators?

These questions are not answered easily. Data from trial runs with SLF in cement kilns in the UK and elsewhere, for example, tend to show significant variation and it is difficult to form quantitative conclusions. Emissions are also usually measured on other types of operation, such as incinerators. However, data to identify the effect of increments of waste of specified composition are not generally available.

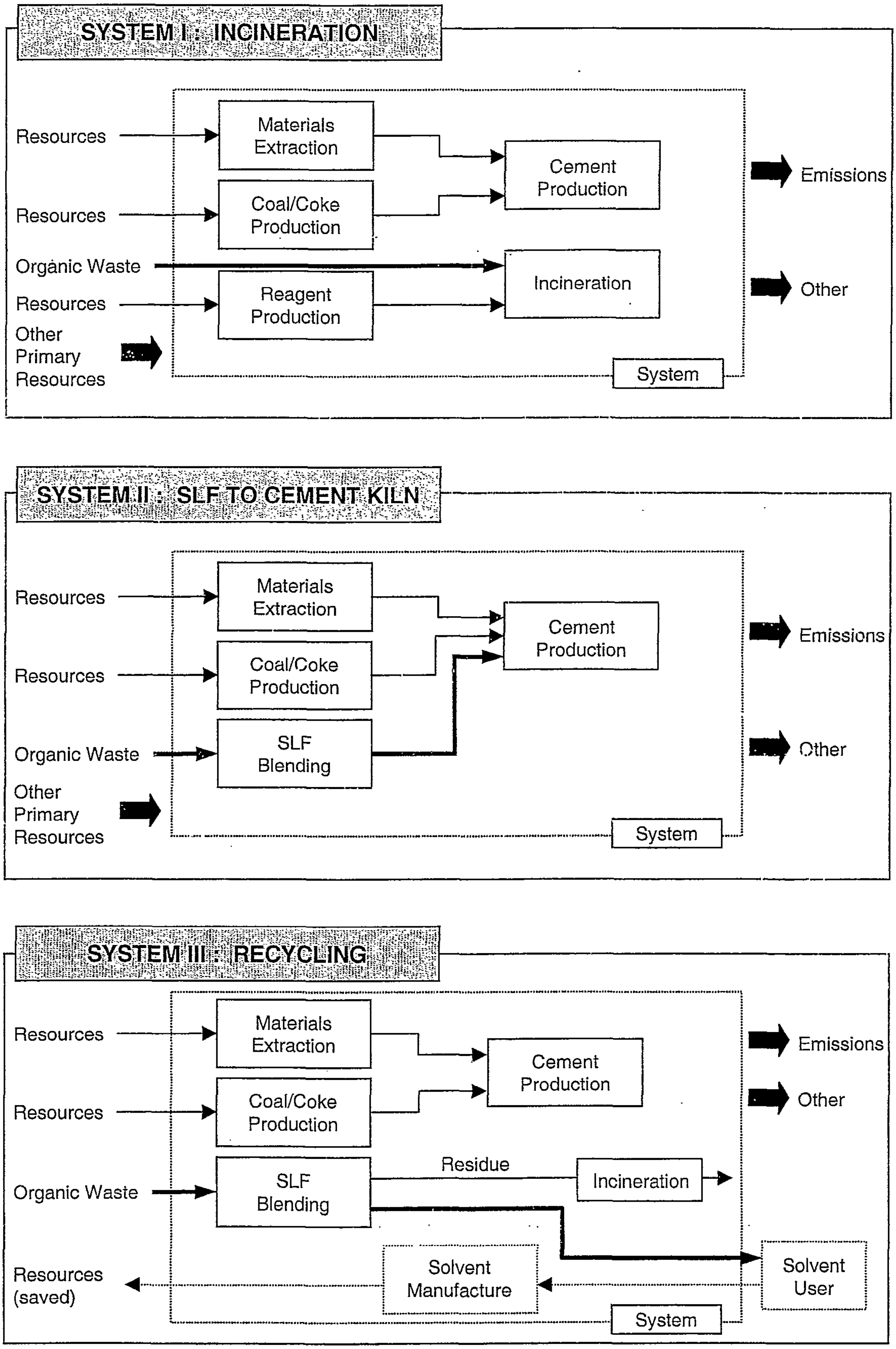

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Figure 3.2 LCA systems compared in the study

The approach taken is therefore to use the best available data for partitioning of pollutants between media. When conclusions are dependent on the assumptions of partitioning, this is considered in the review of results.

Some variables, such as volume of flue gas and quantity of carbon dioxide, can be estimated from the waste analysis, and this forms part of the calculation method.

It is therefore necessary to model the technical operations in a way that is usually not required in LCA. In practice, emissions are very dependent on the control of the operation. The changes predicted by the (rather crude) modelling used for SLF disposal would apply to facilities that are controlled well and run steadily.

(g) Limitation

There is one very important limitation to the analytical technique. The SLF specification imposed by the Environment Agency – on each cement kiln authorised to use it – relates to blended SLF up to a certain quantity. One purpose of the study is to review whether there are some wastes that should not be permitted to be blended into SLF. This requires the analysis of the impact of a small quantity of wastes of specified composition. However, the environmental impact of the subject waste may depend upon the quantity. Certain pollutants will be absorbed in cement clinker up to a quantity – theory suggests – at which breakthrough occurs.

This discontinuity in the effect of certain pollutants versus quantity means that:

- extreme caution is needed in drawing inferences on the impact of small quantities of component wastes in total SLF.
- the principle of exclusion of certain wastes from a blend may be difficult to justify rigorously.

3.1.3 Methodology

These notes relate to detailed issues of LCA methodology. Some readers may wish to skip this and turn to Section 3.2.

(a) Goals

The purpose of the LCA is to identify the environmental impacts associated with the different ways of disposing of SLF-type wastes.

Data are intended to relate to systems and facilities in the United Kingdom in or around 1997. The plants from which information was obtained comply with current UK environmental regulations. They represent actual good practice rather than necessarily state-of-the-art, although in some cases these are the same.

More generalised data have been used, for example, for internationally traded commodities such as solvents. Good current EU practice is the basis here.

(b) Functional units

Any LCA analysis is based on a "functional unit" to permit comparison of systems fulfilling the same need.

The functional unit for this study is disposal of one kilogram of SLF-type waste before any blending or processing. Different chemical compositions of waste are used in various cases.

(c) Systems boundaries

The boundaries of the systems studied are:

- where the SLF-type waste arises in drummed form or loaded into road tankers
- where raw materials including fuels (including for power and transport) are extracted from the environment; burdens involved in exploration, establishment of extraction facilities and infrastructure, and activities such as agricultural nurseries are outside the boundaries
- where emissions to air and water occur, after any on-site treatment of wastes
- where final residual wastes are landfilled.

Emissions and solid wastes from waste incineration are included. Leachate and gas from landfill are not considered. As noted in Section 3.1.2, the SLF-type wastes should not be landfilled; any final residues sent to landfill will be substantially inert in this analysis.

The life cycle includes transport by appropriate means between stages, and operations for the production of power and fuel from primary sources. General operating burdens, such as from space heating or site transport, are included where possible.

The following exclusions apply:

- Production of capital equipment is excluded. This is likely to introduce a possible significant inaccuracy only in transport, where a sensitivity check has been performed to ensure that the effect of this omission is small.
- Activities of humans involved in the operations, such as travel to work, are excluded as being largely independent of the system.
- Upstream production burdens of minor materials are excluded when they are less than two percent of the total feedstock mass; they are added in as the closest analogous material, however, and possible environmental issues in upstream production are considered qualitatively.

(d) Data sources

Data have been obtained from several sources.

- Information has been received from several of the parties with an interest in SLF, including blenders, cement plants, recyclers and incinerators. Part of the information is publicly available, but some is not. The data are not broken out by plant and represent typical rather than individual facilities.

- Chem Systems' in-house technoeconomic data include considerable information on processing operations. Most are based on information from production companies or have been subsequently confirmed by them. The focus of these data is on material usage, utility consumptions, and major effluents. Emissions data are supplemented as necessary from environmental auditing work, from data supplied in the course of technical studies and, where these are not available, by engineering calculation. This source is particularly useful for the burdens involved in producing new solvents.

- Information compiled in the course of other LCA studies is another source. This includes data and models from Chem Systems' own LCA studies and industry ecoprofiles produced by associations such as CEFIC.

- Technical literature is a final source. This is useful, not so much for basic data such as energy consumptions, but to assist in modelling the combustion of SLF and assessing impacts.

(e) Calculation of the inventory

Some principles are outlined in Section 3.2, on analytical framework, indicating the need for technical modelling of some of the most important aspects of this LCA.

Other points relating to calculation methods are as follows:

- a broad check for mass balance consistency is made for each operation in the systems

- where one operation results in more than one product, the burdens of the operation are shared over all the products with a beneficial end-use, usually on the basis of mass

- the LCI is calculated using an Excel spreadsheet model for maximum flexibility.

(f) Reporting of Life Cycle Inventory

The LCI information is presented as follows:

- total masses of feedstocks are noted; the data for coal, oil and gas do include the consumption of these materials for processing energy and standard energy models have been used for this

- energy use is split into non-renewable feedstock, processing energy, and transport; it is expressed as LHV (Lower Heating Value)

- emissions to air, water and solid wastes to land are reported as masses.

One methodological point of note is that the energy content of the waste itself is not shown in the LCI. Some analysts prefer to record energy content of wastes because the energy is still available for use if the waste is recycled, for example. Others recognise that the practical utility of the calorific value is lost in many circumstances, such as dispersion in an inert medium.

As elsewhere in the analysis of SLF use, the emphasis is on the difference between options rather than the absolute values. With solvent recycling, for example, the solvent passing to the consumer will have the same energy content in the system with recycling and the system with use of new solvent.

It is desirable in an LCI to quote emissions data broken down into individual species as far as possible. In reality, it is very difficult to get consistent reporting of this sort. Many producers simply do not record the appropriate data and LCI or ecoprofile data produced by others are often expressed in a condensed format. Data have been recorded in as much detail as possible by Chem Systems. However, it would be erroneous to draw conclusions that may be affected by the completeness of data available from different operations. The emissions are therefore presented in a restricted number of categories. Some of these are themselves aggregates, such as hydrocarbons or dissolved solids. Where a process-specific emission is known to occur, but is not reported elsewhere, this is noted in the analysis.

(g) Environmental Impact Assessment

Many of the conclusions in an LCA can be drawn from the Life Cycle Inventory. If there are trade-offs between options, or, if prioritisation of impacts is required, then further analysis may be required. It is important to note that LCA is usually not location-specific. In other words, impact assessment techniques as used to date typically exclude considerations of actual conditions of the receiving media or ecosystem, and the dispersion characteristics of the emitted stream. When analyses are used to inform longer term policy decisions, it is not appropriate to produce results that depend on the peculiarities of any site. Such factors would, of course, be considered by Inspectors in reviewing IPC and BPEO for a site.

There are no scientifically exact methods of converting the LCI data into an assessment of the overall environmental benefits or penalties of different systems. Several techniques are used.

A first step is often to group burdens into categories of contributions to particular environmental issues. Carbon dioxide and methane contribute to global warming, for example. Sulphur dioxide is a contributor to acid rain and to human health issues. All contributors to a single issue can be expressed as a common currency. Global warming agents can be expressed in kilograms of CO_2 by using global warming potentials. Other weighting factors may be less scientifically supportable. Considerable academic work has been performed in this field by the University of Leiden and others.

Other analytical steps may address two further questions.

- How great a contribution does the system studied make to the total issue, regionally or globally? What percentage of European global warming burdens is emitted, compared to what percentage of total tropospheric ozone precursors, for example?

- How important is each environmental issue? Is acid rain a more serious problem than eutrophication, for example?

There are strong areas of commonality between this type of methodology and elements of the approach proposed for BPEO assessments for IPC (Technical Guidance Note E1). The BPEO methodology does not cover as broad a range of issues as are usually addressed in LCA. It also requires estimation of the contribution of the process to, for example, ambient air concentrations. This implies some form of dispersion modelling, which would take into account plant-specific factors.

The approach taken in the LCA on SLF is therefore:

- to draw conclusions as far as possible from the LCI alone

- to use relevant factors from the BPEO methodology in any further assessment of options.

3.2 Life Cycle Inventory Calculation

3.2.1 Wastes and Fuels Studied

One purpose of the study is to identify types of waste that should not be used in SLF. It is almost impossible to do this by naming certain sources and categories of waste because the compositions differ widely within each category. Therefore, the identification of excluded wastes must be based on composition or other definable properties.

Hypothetical waste compositions have been constructed to illustrate the influence of different components on the total results. There are some instances in which the presence of one element affects the impact of another. Mostly, however, the elements can be treated as independent. Therefore, only a few metals are included in the analysis. The messages from the LCI are extended to other metals in the review of results.

Table 3.1 contains the hypothetical waste compositions. The organic compounds include:

- typical blended SLF, with composition derived from limits set by the Environment Agency (although these differ between kilns)

- a high hydrocarbon (and high energy) waste, such as a waste hydrocarbon solvent, with the chemical species taken as toluene

- an oxygenate, such as a waste solvent stream from a paint application, with a high metal content and the organic chemical taken as acetone
- a chlorinated waste such as non-recyclable residues from metal degreasing; this is trichloroethylene with a high metal content
- an aqueous stream with a negligible energy content, in this case methanol in a solution containing 85 percent water
- an oily waste, with composition similar to that of used lube oil.

Energy contents vary widely; these are based on approximate calculations. Other components are also varied but do not necessarily match the organic compounds in real wastes.

Table 3.1 Composition of wastes studied in LCA(1)

	Unit	I	II	III	IV	V	VI
		Typical SLF	Hydrocarbon	Oxygenate	Chlorinated	Aqueous	Oily
Main compound		Mixed	Toluene	Acetone	Trichloroethylene	Methanol	Oil
Carbon	%	54.0	82.5	52.5	14.3	5.1	80.4
Hydrogen(2)	%	7.9	7.9	8.8	1.8	1.7	9.0
Oxygen(2)	%	27.0	0.5	23.3	0.1	6.9	0.5
Sulphur	%	0.5	2.5	0.1	0.1	0.1	0.5
Chlorine	%	1.5	0.1	0.1	63.5	0.1	0.03
Nitrogen	%	0.1	1.0	0.1	0.1	0.1	0.1
Chromium	ppm	200		300	300		10
Lead	ppm	500		300	300		
Mercury	ppm	10		50	50		
Ash	%	4.0	0.5	5.0	15.0	1.0	2.0
Free water	%	5.0	5.0	10.0	5.0	85.0	7.5
Energy (LHV)	MJ/kg	24.7	37.3	25.9	11.9	(1.3)	37.7

(1) Components in real wastes do not necessarily coincide as shown in the table.

(2) Not including H_2 and O_2 in free water.

The composition of cement kiln fuels is also of relevance. Table 3.2 presents the basis for the LCA, drawn from trial reports for Barrington cement works. In reality, the composition on any kiln may differ from this and the conclusions on environmental impacts could also differ.

Table 3.2 **Compositions of coal and petcoke**

		Coal	Petcoke
H	%	5.000	2.000
O	%	7.000	3.000
S	%	1.000	5.000
Cl	%	0.200	0.055
F	%	0.001	
N	%	1.500	
Sb	ppm	3	1.1
As	ppm	67	1.5
Pb	ppm	90	17.5
Cr	ppm	60	2.5
Co	ppm	6	2
Cu	ppm	70	4.5
Mn	ppm	140	45
Ni	ppm	50	300
V	ppm	85	1 000
Sn	ppm	51	0
Hg	ppm	1	0.1
Cd	ppm	1	
Ash	%	11.213	0.500
H_2O	%	4.000	1.000
Energy	MJ/kg	26.	31

The main parts of the total LCA system – incineration, cement production, and solvent recycling -- are described below.

3.2.2 Incineration system

(a) Description of system

Figure 3.3 shows the elements involved in high temperature incineration. Only the main components are shown for simplicity. Items such as intermediate steps in the production of reagents, the chain of operations in power production, or transport between stages, are covered in the LCI calculations but not shown on the diagram.

There are various designs of high temperature incinerator that are suitable for destruction of organic waste. Chem Systems interviewed Cleenaway, Rechem, and SARP UK. The system on which the LCA is based is not any single plant, but is reasonably typical of units suitable for chlorinated waste.

Incinerator operators need a certain calorific value of waste to achieve the required combustion temperatures. The "burn menu" therefore includes the combination of wastes to meet that need and any other constraints such as halogen load. Combustion occurs at, typically, 1 200 °C or more. Secondary fuel is used if needed to achieve this. A key part of the design requirement is to avoid formation of dioxins and furans. Temperature, residence time, and oxygen content ensure breakdown of components in the combustion stage. It is also essential to cool the gases quickly through the temperature range at which dioxins and furans are most likely to form, around 200 °C to 450 °C. This may be achieved by indirect cooling or by water quench, for example. Waste heat recovery boilers are an option in achieving this duty, but operators typically prefer to focus on achieving environmental performance without the constraints of boiler requirements.

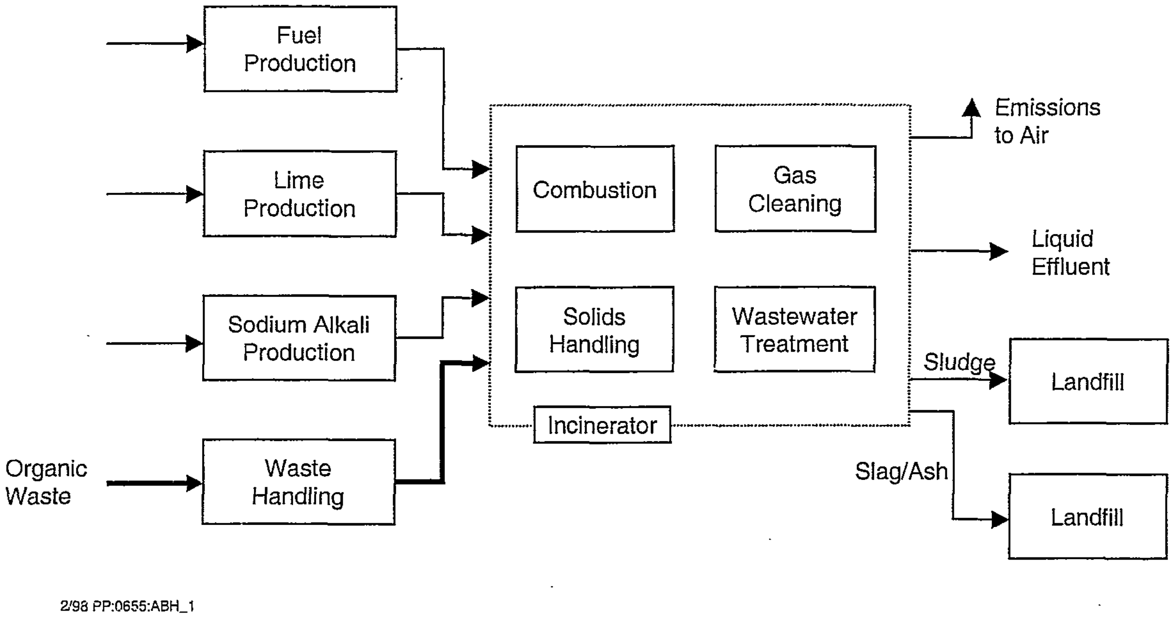

Figure 3.3 Simplified incinerator system

Gas cleaning requirements are stringent to permit the regulatory requirements to be met. Acid gases such as HCl and SO_2 need to be scrubbed out. Particulate matter and adsorbable components must also be removed. The LCA is based on a gas cleaning system with water scrubbing followed by scrubbing with sodium alkali solution. Lime is injected and removed in a bag filter before the flue gas is reheated and sent to stack.

Liquid effluents from the scrubbing system are neutralised and treated before discharge. In addition to sludge from this operation, other solid wastes include slag or ash from the combustion chamber and the bag filter. All the solid wastes are assumed to be treated as special wastes and sent to appropriate landfills. The organic content of these wastes is negligible, so no landfill gas will be produced. Leachate will be carefully controlled at special waste sites.

There are various other operations included in the incinerator system, such as those associated with on-site and external use of transport. Of particular relevance to incineration are the reagents used in gas cleaning. The upstream operations therefore include the production of caustic (sodium hydroxide) in a chloralkali plant and the burning of limestone in a vertical shaft kiln to produce lime.

It should be noted that there is a trend in the EU to require hazardous waste incinerators not to emit liquid wastes. A review of the LCI results indicates that this would not affect the conclusions of the study.

(b) LCI development

The LCA is calculated on the basis of one kilogram of SLF-type waste. As noted in Section 3.1, some form of approximate technical modelling is required to identify the effects of different waste compositions. The approach taken is described below. Numerical values are derived from elements of operator data supplied in confidence. Sensitivity to the assumptions is reviewed qualitatively in the commentary on LCI findings.

- For a waste with a low energy content, supplementary fuel is assumed to be added until the combined waste and fuel has a calorific value of 18MJ/kg. It is implicit that the incinerator was previously operating with a suitable burn menu and that the SLF-type waste is an additional load. The supplementary fuel is taken to be gas oil (diesel). As noted in Section 3.1, the economic effect of high calorific value SLF wastes (in permitting low energy wastes to also be burnt) is not considered.
- From the composition of the waste (and supplementary fuel if needed), the total quantity of flue gas is calculated. All carbon is taken to be combusted, with carbon monoxide at 0.01 percent of carbon dioxide by mass.
- The mass emission of certain elements in flue gas is related to flue gas volume, dry with 11 percent oxygen. Final particulate emissions are taken at 4 mg/m^3 and of NOx at 350 mg/m^3 plus the NOx equating to the nitrogen content of the waste and fuel.
- Other elements in the waste and fuel are taken to be partitioned between the various outlet streams as noted on Table 4.3 below. This partitioning is very approximate, and is based on data that include estimates of partitioning in municipal waste incinerators. Full mass balance data on hazardous waste incinerators were not available.

Table 3.3 Partitioning of waste elements between incinerator output streams (percent)

	Slag/ash	Sludge	Liquid effluent	Flue gas
Sulphur	10	10	Rest	2
Halogens	20	Rest	10	0.1
Mercury	Rest	15	2	10
Other metals	Rest	15	2	0.5

- Estimation of mass emissions of dioxins and furans is perhaps the most controversial part of the calculation method. These compounds are produced by reactions involving chlorine, hydrogen and carbon. When tests have been performed on municipal waste incinerators, the quantities of dioxins have been found to be unaffected by incremental quantities of chlorine in the feed. The operating conditions and control of the incinerators are one of main determinants of dioxin emission. No link is therefore made in the modelling with chlorine content (or hydrocarbon content) of the waste. Instead, dioxin and furan emissions are taken being process-specific rather than waste-specific, at 0.1 ng/m^3 (TEQ) of flue gas.

- The quantities of neutralisation reagents are calculated using excesses on stoichiometric requirements. The relationships are deduced from operating data.
- Quantities of effluents and solid wastes are also calculated by a mixture of empirical data and stoichiometry.

3.2.3 Cement Kiln System

(a) Description

The cement kiln system is shown in simplified form in Figure 3.4. A good process overview is provided in the IPC Guidance Note S2 3.01. The following brief summary draws on this source, interviews with producers, and technical literature.

The main raw materials to a cement kiln are limestone or chalk and clay or shales. Raw materials are obtained from own quarries, or by purchase, and undergo size reduction and blending. They are calcined and sintered to form clinker. The clinker is ground with around three to eight percent of gypsum to form the final cement product.

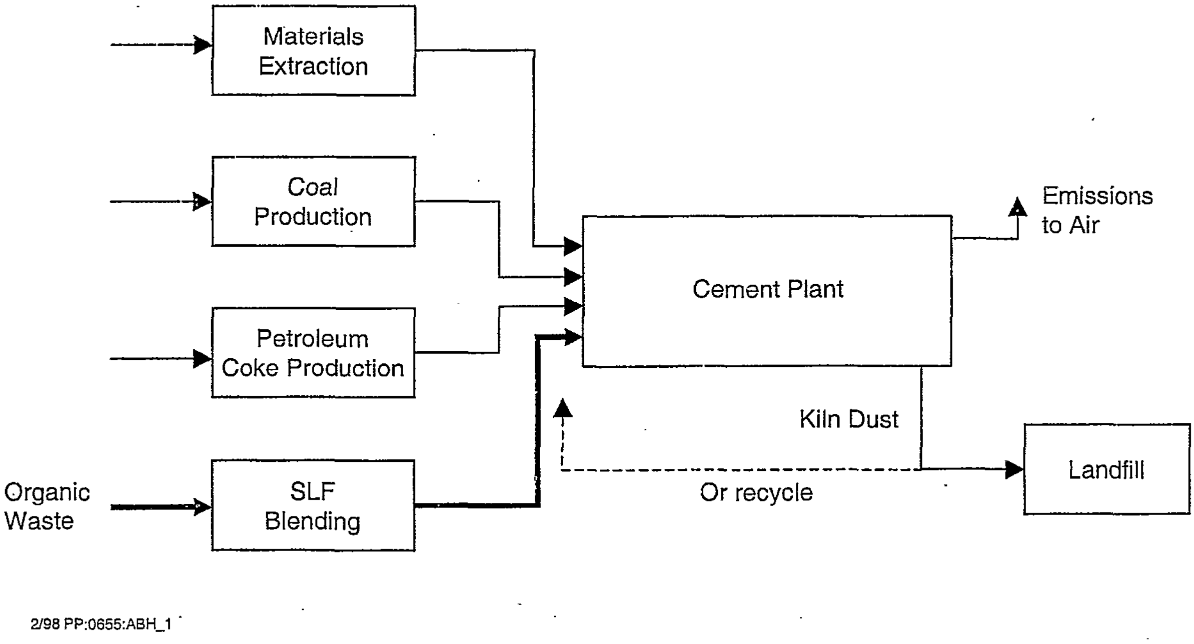

Figure 3.4 Simplified SLF to cement kiln system

Various fuels may be used in cement kilns. Apart from SLF, the most common for economic reasons are coal and petroleum coke. The petroleum coke is a product of refineries that are configured to produce it. Only one UK refinery falls into this category. Petroleum coke typically contains a significant percentage of the sulphur in the crude oil feeding the refinery.

Sulphur in petcoke may be up to around six percent by weight. Relatively high levels of other contaminants may also be present.

In the cement kiln system itself, the cement materials travel counter-current to the fuel and combustion gases. The cement materials are first dried, then calcined at around 800-900 °C, with the release of carbon dioxide as the limestone decomposes. Sintering occurs at approximately 1 450 °C after which the temperature is reduced to around 1 100 °C to form stable crystals. A clinker cooler reduces the temperature to about 250 °C.

There are several types of cement process, depending on whether the raw materials are fed as a slurry or dry. The four main variants are:

- wet process, with a slurry feed
- semi-wet process, where the slurry is filter pressed and fed directly or via a preheating device
- semi-dry process, where dried ground material is nodulised with water, and dried and partly calcined in a grate preheater
- dry process, where raw material is preheated in cylcones, possible incorporating a precalcining stage.

The energy requirement differs between processes. Table 3.4 shows typical data.

Table 3.4 Fuel consumption per tonne of clinker

Process	Energy *(MJ/kg clinker)*
Wet	6.05
Semi-wet	4.80
Semi-dry	3.55
Dry	3.55

Source: IPC GN S2 3.01 (converted to MJ approximately)

(b) Emissions from cement kilns

The main sources of emissions from cement kilns are gases from the kiln and associated systems, and cement kiln dust (CKD), that is removed as a solid waste. On some cement kilns, the CKD is completely recycled. It is reasonable to assume that the contaminants in the CKD will mostly be contained in the clinker when CKD is recycled. The implication of this is considered in the review of results in Section 3.3.

The focus of the SLF study is the impact of changes in fuel composition, not the impact of the total cement production operation. The technical issues are complex and are not easily quantifiable.

Sulphur oxides

Sulphur compounds occur in various forms both in the raw materials and in the fuels. A very large proportion of the sulphur in the fuels is likely to convert to sulphur dioxide (SO_2) in the hot part of the kiln. Significant proportions of sulphur in the raw materials will also be converted to gaseous SO_2. As the kiln gas moves to the feed end, SO_2 will be absorbed.

In a wet process kiln, the reabsorption occurs in the dust cloud and in zones fitted with chains at the wet feed end. The total retention varies with the particular chemistry, operating conditions and design features of the kiln. The total retention may be in excess of 90 percent but could be as low as 70 percent.

Retention is usually higher in a preheater or a precalciner dry process plant. Here, unreacted lime in cyclone preheaters acts as an adsorbent. Sulphur present as sulphides will tend to be released at lower temperatures where free lime content is lower, and so absorption of this material will not be effective. Sometimes, a gas by-pass is operated to avoid problems of choking in the cyclones. This can be a source of high SO_2 emissions unless abated.

When considering a unit of additional sulphur in fuel, it is reasonable to suggest a sulphur removal efficiently in a preheater/precalciner system of up to, say, 95 percent. For the wet process, scrubbing efficiency (as opposed to the total retention) is less clear. From the Environment Agency report on the Barrington works, an efficiency of less than 70 percent could be inferred. In both cases, it must be recognised that SO_2 absorption relies on the natural alkalinity of the raw materials and so there must be some sulphur loading at which breakthrough would occur.

Nitrogen oxides

Nitrogen oxides produced in cement kilns are primarily thermal NOx rather than those derived from nitrogen in the fuel. Up to 60 percent of fuel in precalciner kilns is burnt in the calciner stage, at temperatures too low for high rates of NOx formation. In the wet process, all fuel is burnt in the sintering zone, at 1 450 °C when NOx will be generated.

Chlorine

Chlorine in the raw materials and the fuels fed to the kiln system can form volatile compounds with metals such as potassium. These can condense or be absorbed in clinker or CKD in cooler parts of the kiln. Empirical data (Burning Hazardous Waste in Cement Kilns, ETI, 1992) suggest that a substantial increase in chlorine content of the fuel will result in increased gaseous emissions of chlorine compounds measured as HCl. However, this does depend upon the total quantity of chlorine entering the kiln. Chlorine content is actually added intentionally to some cement kilns to balance the chemistry. The Environment Agency imposes low chlorine limits (typically 1.5 percent) on blended SLF.

Metals

Metals and their compounds fall into three classes:

- refractory (relatively non-volatile), including barium, beryllium, chromium, arsenic, nickel, vanadium, aluminium, titanium, calcium, iron, manganese and copper
- semi-volatile, such as antimony, cadmium, lead, selenium, zinc, potassium, and sodium
- volatile, such as mercury and thallium.

Kiln exhaust gases typically contain under 0.1 percent of refractory metals and under 0.5 percent of semi-volatile metals entering the kiln.

However, the presence of chlorine has been shown to influence the emission of semi-volatile metals in tests on SLF usage (the ETI report cited above). With heavily chlorinated SLF, there is a tendency for increased emissions of lead and cadmium for example.

Emissions of volatile metals such as mercury tend to increase with the content in the fuel.

One further point to note is that the retained metals tend to concentrate in the kiln dust (CKD) because of the cycle of volatilisation and condensation. Tests on CKD indicate that leachability of metals is very low, irrespective of the kiln fuel used. If CKD is recycled, the contaminants will be spread over the mass of the clinker.

Organics

The very high temperatures of the sintering zone ensures very high destruction efficiencies of organic materials, which should be comparable to those in high temperature incinerators. The "de novo" formation of dioxins and furans can occur in a temperature range of around 200 °C to 450 °C, as the gases cool. It could be argued that the residence time in this temperature range is longer for a kiln than an incinerator, so dioxin formation could be greater. Measurements on the Barrington works indicated initially rather high dioxin figures with SLF, which dropped to very low and consistent levels in later runs. This is taken to reflect the influence of operating conditions as there is no consistent relationship with fuel composition in the tests. In practice, the concentration of dioxins in flue gas is similar for cement kilns and incinerators.

(c) LCI Development

The calculation of the LCI for one kilogram of SLF entering a cement kiln follows very similar principles to those used for incineration.

- Carbon monoxide is calculated at 0.2 percent of carbon dioxide. Other pollutants estimated from flue gas calculations are particulates at 30 mg/m^3, NOx at 900 mg/m^3 for wet kilns (the IPCGN benchmark) plus that from nitrogen in the fuel, and dioxins/furans at 0.1 ng/m^3 (TEQ). A lower NOx concentration of 450 mg/m^3 is used for dry kilns, in recognition of the lower temperatures in precalciner processes. All are calculated on flue gas with 11 percent free oxygen, dry.

- Table 3.5 shows how other elements are assumed to be partitioned between kiln dust and final stack gases. The remaining part of each element ends in the clinker product. Data are derived from empirical results, including a metals mass balance from one operator, but are approximate. The exact figures would depend upon the specific kiln conditions, including feedstock compositions.

Table 3.5 Partitioning of waste elements between cement kiln output streams (percent)

	Wet Process		Dry Process	
	Kiln Dust	Flue Gas	Kiln Dust	Flue Gas
Sulphur	10	30	10	5
Halogens [1]	10	1	10	1
Mercury	20	25	20	25
Cr, Co, Cu, Mn, Ti, V, Ni	5	0.1	5	0.1
Pb	5	0.2	5	0.2
Sb, Sn	5	1	5	1
As	10	1	10	1
Cd	20	1	20	1

[1] HCl measured as HCl, not including metal chlorides

To allow for the substitution of other fuel by SLF, the incremental impacts of cement production are calculated for 50 MJ of fuel. If no SLF is burnt, the 50 MJ is coal and petcoke. If one kilogram of SLF is burnt, the quantity of other fuels is reduced. Combustion gases are calculated on the combined fuel mixture.

Data are calculated for a wet process and a preheater/precalciner dry process. The quantity of clinker, and associated impacts, is different in these cases. Both relate to 50 MJ of fuel. The 50 MJ figure is introduced for computational convenience only; it is not relevant to the differences between disposal routes of SLF-type wastes.

3.2.4 Solvent Recovery System

(a) Description

Figure 3.5 shows the solvent recovery system included in the LCA comparisons. The SLF-type waste is distilled to recover solvent or other usable product. There are two main groups of product. One is mixed solvents for general purpose use, often known as thinners.

The other is that of single solvents, such as acetone or toluene. A recovery of around 60 to 70 percent is typical. Solvent recovered beyond a certain point will tend to be coloured or otherwise contaminated. At least one solvent recycler claims recovery efficiencies of around 80 percent, including reprocessing of the coloured material to achieve commercial purity. However, this is not always technically feasible for reasons that can include corrosion or fire risks. Addition of neutralising agents may be needed to control corrosion. The extent of recovery is an important factor as residues from solvent recycling are a possible feed to SLF blending.

A number of streams are produced in addition to the solvent residue. Some, like oil from vent scrubbers, may be recycled. Others, such as seal water from vacuum systems, may not be commercially recyclable. The waste streams are shown on Figure 3.5 as being sent to high temperature incineration. With deeper recovery, the residues may be inerts and waxy organics that are suitable for landfill.

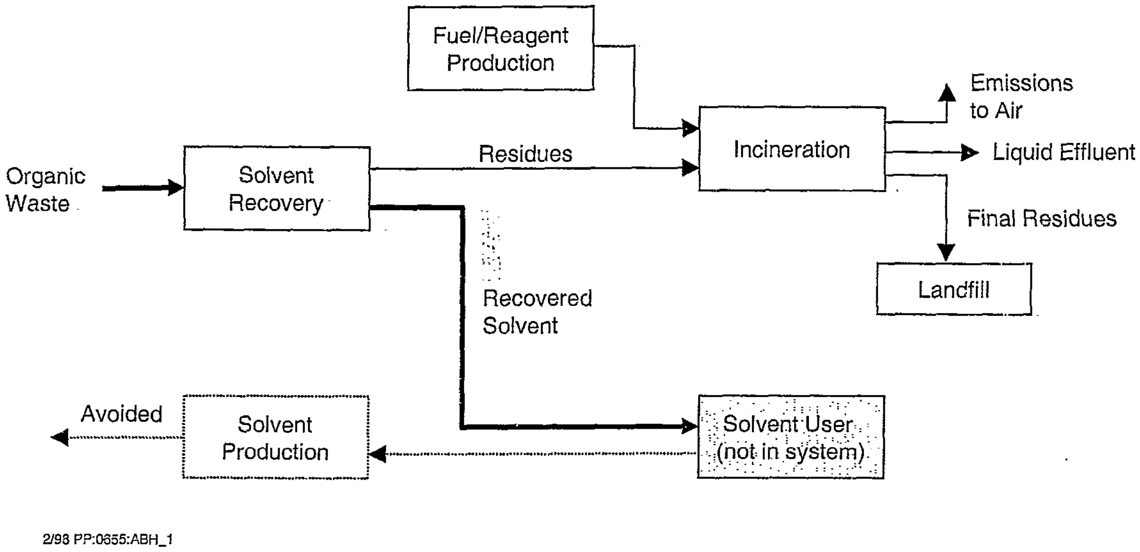

Figure 3.5 **Simplified solvent recovery system**

The recovered solvent is used in various applications that do not form part of the LCA system. The supply and demand of recycled solvent varies over time, and this can be reflected in pricing, particularly of thinners grade. Nonetheless, it is reasonable to assume that new solvent would need to be supplied to the user if recycled solvent were not available. Therefore the LCI includes the avoided burdens of producing new solvent (see Section 3.1 for discussion of the analytical framework).

A number of materials are considered in the various cases. The materials and production routes for new material are summarised below.

- **Toluene** is recovered by solvent extraction from hydrocarbon streams from catalytic reformers on refineries, and other aromatic streams. The original feedstock is crude oil, which passes to refineries and, as appropriate, other process units. Ecoprofile data from the European industry association APME are used.

- **Acetone** is produced mainly as a co-product with phenol. The main feedstocks to the production of phenol and acetone are propylene and benzene, with cumene as an intermediate. Chem Systems' in-house data are used for this step. Propylene is one of the products from the steam cracking of naphtha and other hydrocarbons. Benzene is produced by several processes, including extractive distillation of another product stream from steam cracking. APME data are used for the production of propylene and benzene starting with crude oil.

- **Trichloroethylene** is typically produced on integrated complexes where ethylene and chlorine are used primarily to manufacture ethylene dichloride (EDC) and VCM. Chem Systems' data are used for the production of trichloroethylene itself, and APME data for upstream steps.

- **Methanol** is produced by the manufacture of synthesis gas from natural gas, followed by catalytic synthesis. Chem Systems' in-house data are used for the LCI.

One of the hypothetical waste streams is an oily waste, such as used lube oil. In the UK, the most common form of recovery is by light processing and use as fuel. The process involves settling, aided by chemicals and warming, with disposal of sludge. Recovered fuel is typically used to dry limestone or hard rock for roadstone production, instead of gas oil. In the LCI, this is treated as a sub-set of incineration where the SLF is a substitute for usual fuel (see Section 3.5.4).

(b) LCI Development

In the case considered, the solvent residues are sent to incineration. To analyse this, the composition of the residue is calculated assuming that substantially all the unwelcome components remain in the residue. The incineration model is then run using this composition.

Data for the recycling process and supporting transport and other elements are taken from information supplied by operating companies.

3.3 Life Cycle Inventory Results

3.3.1 Incineration and SLF to Cement Kilns

The Life Cycle Inventory data are expressed in units of mass per kilogram of SLF waste. The data are calculated back to show total mass of coal extracted from the environment, for example, and total emissions from the full system considered. Operations such as power generation are included, so that use of materials and emissions associated with all operations in the systems are in the inventory. This explains the presence on the inventory tables of some burdens that may not be associated with the core disposal options.

It is important to note that the systems compared are defined in a way that permits the differences between the disposal routes for waste to be identified. For example, the cement kiln impacts included in each system are those corresponding to the consumption of 50 MJ of fuel. This is to permit the displacement of conventional fuel with SLF of differing energy contents to be considered. The absolute values of burdens of each system are therefore not of primary importance. For definition of Systems I to III, see Section 3.1.

The LCI results for a comparison between incineration (System I) and SLF in a cement kiln (System II) are shown in Table 3.6. The data are based on a wet process cement kiln. System I includes a cement kiln using conventional fuel only. If the differences are positive, or if System II impacts are lower than 100 percent of System I, then there is an advantage in the SLF route.

The basis of the numerical values in Table 3.6 may not be obvious. The following points may be of assistance.

- The absolute values of environmental burdens from the cement kiln relate to 50 MJ of cement kiln fuel (see above) while those for the incinerator are for one kilogram of SLF-type waste. The absolute values relating to the cement kiln are therefore systematically higher than for the incinerator.
- The cement kiln data include the combustion of some conventional fuels – coal and petcoke – even when SLF is also burnt. The emission of SO_2, for example, from burning SLF-type waste cannot be directly compared for an incinerator and cement kiln by examining absolute values in the table: the difference is the importance figure.
- Data in Table 3.6 include those relating to auxiliary operations within the system. For example, the total cement kiln system includes the processing operations necessary to produce petcoke. Power generation and production of transport fuel are also included. Emissions may be significantly higher from the system than from the cement kiln itself. This explains the presence of emissions to water in the cement kiln system, and relatively high levels of hydrocarbon emissions to air, for example.

Table 3.6 Life Cycle Inventory data: incineration system and SLF to wet process cement kiln

All data expressed per kg waste		SYSTEM I INCINERATION			SYSTEM II CEMENT KILN	DIFFERENCES	
	Units	Incineration *With SLF*	Cement Kiln *No SLF*	Total	Wet Process Cement Kiln *With SLF*	System I *minus System II*	System II as *% System I*
MATERIALS							
Coal	kg	0.05	1.40	1.44	0.80	0.65	55%
Oil	kg	0.01	0.82	0.83	0.45	0.38	54%
Gas	kg	0.01	0.03	0.04	0.03	0.01	79%
Iron ore	kg	0.00	0.08	0.08	0.08	0.00	100%
Limestone	kg	0.01	7.09	7.10	7.09	0.01	100%
Bauxite	kg	0.00	0.00	0.00	0.00	0.00	51%
NaCl	kg	0.01	0.00	0.01	0.00	0.01	0%
Sulphur	kg	0.00	0.00	0.00	0.00	0.00	0%
Clay	kg	0.00	3.04	3.04	3.04	0.00	100%
Sand	kg	0.03	0.00	0.03	0.00	0.03	0%
Water consumed	kg	25.29	8.82	34.12	8.16	25.96	24%
ENERGY							
Total feedstock	MJ	0.04	0.00	0.04	0.00	0.04	0%
Processing: renewable	MJ	0.23	1.09	1.31	1.01	0.30	77%
Processing: non-renewable	MJ	2.39	73.32	75.71	41.75	33.96	55%
Transport energy	MJ	0.17	1.72	1.89	1.99	-0.10	105%
Total Energy		2.82	76.12	78.95	44.75	34.20	57%
EMISSIONS TO AIR							
CO2	mg	2 090 378	9 250 213	11 340 590	8 473 535	2 867 056	75%
CO	mg	328	17 319	17 646	16 269	1 377	92%
CH4	mg	5	23	28	21	6	77%
General HC	mg	130	2 715	2 845	1 878	967	66%
NOx	mg	5 482	62 498	67 980	52 099	15 880	77%
SO2	mg	844	30 134	30 978	19 627	11 351	63%
NH3	mg	0	0	0	0	0	47%
Dust	mg	104	1 960	2 064	1 778	286	86%
HCl	mg	18	14	32	84	-52	263%
HF	mg	0.5	0.0	0.5	2.6	-2.0	476%
HBr	mg	0.0	0.0	0.0	0.0	0.0	0%
Metals (total)	mg	10.95	3.12	14.08	8.42	5.66	60%
Sb	mg	0.25	0.02	0.27	0.26	0.01	96%
As	mg	0.25	0.08	0.33	0.09	0.24	27%
Pb	mg	2.50	0.59	3.09	2.79	0.29	90%
Cr	mg	1.00	0.07	1.07	0.24	0.84	22%
Co	mg	0.50	0.01	0.51	0.10	0.40	20%
Cu	mg	3.00	0.09	3.09	0.64	2.44	21%
Mn	mg	1.25	0.19	1.44	0.35	1.10	24%
Ni	mg	0.25	0.24	0.49	0.17	0.32	35%
V	mg	0.25	0.72	0.97	0.41	0.56	43%
Sn	mg	0.50	0.06	0.56	0.13	0.43	23%
Hg	mg	1.00	0.31	1.31	2.65	-1.34	202%
Cd	mg	0.20	0.01	0.21	0.20	0.00	98%
Dioxins	μg	0.0003	0.0045	0.0048	0.0042	0.0005	89%
EMISSIONS TO WATER							
Volume	litres	24.02	1.49	25.51	0.76	24.75	3%
COD	mg	0.11	7.98	8.09	4.42	3.67	55%
BOD	mg	0.04	3.94	3.98	2.16	1.82	54%
Acid	mg	0.12	23.02	23.13	12.39	10.74	54%
Nitrates	mg	0.05	0.99	1.04	0.62	0.42	59%
Sulphates	mg	0.05	0.20	0.25	0.18	0.07	73%
Metals	mg	0.02	3.86	3.88	2.08	1.80	54%
Ammonium	mg	0.10	1.20	1.29	0.81	0.48	63%
Cl	mg	0.05	7.68	7.74	4.14	3.59	54%
Suspended solids	mg	0.27	102.03	102.30	53.18	49.12	52%
Hydrocarbons	mg	0.82	15.35	16.17	9.71	6.46	60%
Other N	mg	0.00	0.77	0.77	0.41	0.36	54%
Total DS	mg	48.84	255.72	304.56	223.53	81.02	73%
Br	mg	0.00	0.00	0.00	0.00	0.00	0%
F	mg	0.0001	0.0000	0.0001	0.0000	0.0001	0%
Sb	mg	0.0000	0.0000	0.0000	0.0000	0.0000	0%
As	mg	0.000001	0.000000	0.000001	0.000000	0.000001	0%
Pb	mg	0.000010	0.000000	0.000010	0.000000	0.000010	0%
Cr	mg	0.000004	0.000000	0.000004	0.000000	0.000004	0%
Co	mg	0.000002	0.000000	0.000002	0.000000	0.000002	0%
Cu	mg	0.000012	0.000000	0.000012	0.000000	0.000012	0%
Mn	mg	0.000005	0.000000	0.000005	0.000000	0.000005	0%
Ni	mg	0.000001	0.000000	0.000001	0.000000	0.000001	0%
V	mg	0.000001	0.000000	0.000001	0.000000	0.000001	0%
Sn	mg	0.000002	0.000000	0.000002	0.000000	0.000002	0%
Hg	mg	0.000000	0.000000	0.000000	0.000000	0.000000	0%
Cd	mg	0.000001	0.000000	0.000001	0.000000	0.000001	0%
SOLID WASTES							
Inert inorganic	mg	22	692 157	692 179	349 977	342 202	51%
Other industrial	mg	16 278	729 266	745 544	726 800	18 745	97%

The results are also shown on Figure 3.6 for selected variables. The burdens from the SLF in current kiln route are expressed as percentages of those from incineration. This shows whether there is a net advantage or disadvantage, but the exact percentages are not of particular significance.

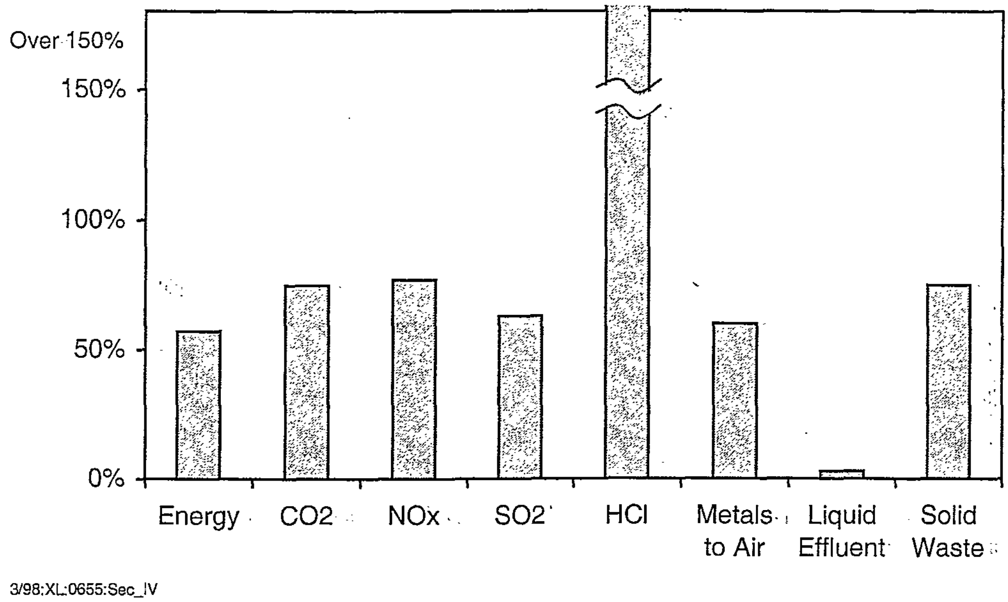

Figure 3.6 SLF to cement kiln (wet process) impacts as percentage of incineration impacts

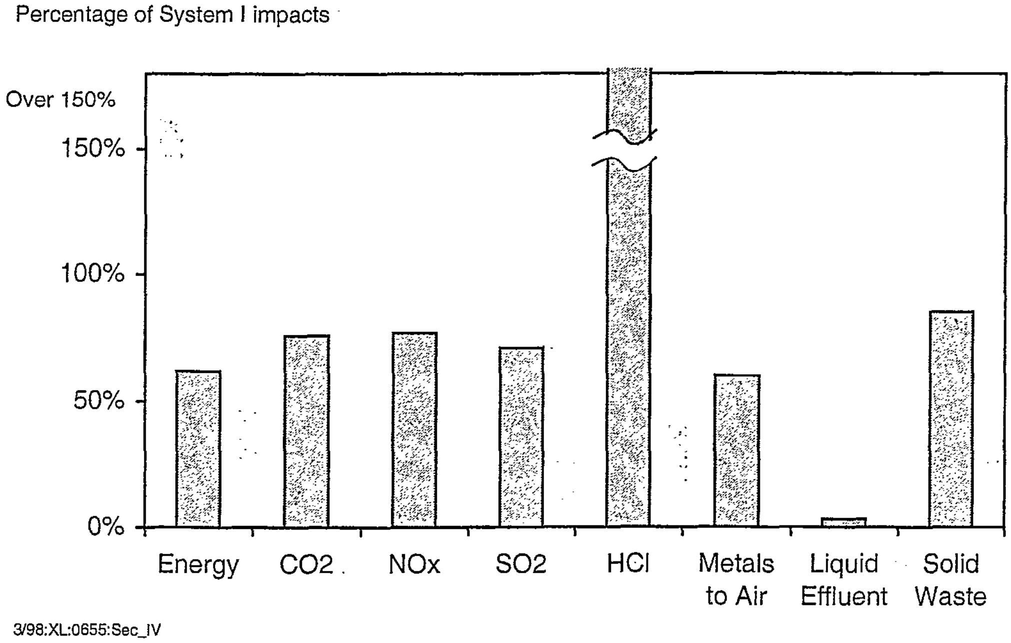

Figure 3.7 SLF cement kiln (dry process) impacts as percentage of incineration impacts

As can be seen, sending SLF to cement kilns rather than incineration is beneficial in many respects. These include energy consumption, and emissions of carbon dioxide, oxides of sulphur and nitrogen oxides. This advantage arises because the SLF is displacing other sources of cement kiln fuel, which would have similar or higher impacts. Table 3.7. shows the emissions of sulphur dioxide to illustrate the point. The incinerator is more effective at SO_2 abatement than the wet process kiln, but the avoided SO_2 from coal and petcoke is the dominant factor.

Table 3.7 Sulphur dioxide emissions (grams per kg SLF)

	System I	**System II**
SO_2 from incinerator	0.8	-
SO_2 from SLF in kiln	-	3.0
SO_2 from other fuel (cement kiln etc)	30.1	16.6

For some of the variables, the SLF to cement kiln route shows a higher environmental burden than the incineration route. Emissions of HCl fall into this category, reflecting the very high scrubbing efficiencies achieved in the gas cleaning trains of incinerators.

With most of the metals emitted to air, System II - the SLF route – shows the advantage. However, caution is needed here as the data on percentage capture in cement kilns and incinerators are not very precise. If total chlorides to the cement kiln increase, there is evidence to indicate that losses of volatile metals can rise as SLF is added. This is not apparent when only 1 kg of SLF is considered.

Dioxins are shown as lower from the SLF route, but it should be remembered that the quantity is calculated on the basis of flue gas volume only in this analysis.

Liquid effluents are lower for the SLF to cement kiln route. This reflects the fact that the incinerator case is modelled on a plant with a wet scrubber system.

If a dry process cement kiln takes the SLF, the conclusions are directionally the same. The comparison is shown in Table 3.8. The data are expressed per tonne of SLF-type waste feed and relevant impacts of cement production are calculated on the basis of 50 MJ of fuel. As with other comparisons, it is the difference that is of interest, not the absolute values. The advantage of switching to SLF in terms of SO_2 emissions is slightly less for a dry process kiln than one operating a wet process, because sulphur retention is in any case higher.

Table 3.8 Life Cycle Inventory data: incineration system and SLF to dry process cement kiln

All data expressed per kg waste		SYSTEM I INCINERATION			SYSTEM II CEMENT KILN	DIFFERENCES	
	Units	Incineration With SLF	Cement Kiln No SLF	Total	Cement Kiln With SLF	System I minus System II	System II as % System I
MATERIALS							
Coal	kg	0.05	1.61	1.66	0.98	0.68	59%
Oil	kg	0.01	0.89	0.90	0.51	0.38	57%
Gas	kg	0.01	0.07	0.07	0.06	0.01	82%
Iron ore	kg	0.00	0.19	0.19	0.19	0.00	100%
Limestone	kg	0.01	16.00	16.01	16.00	0.01	100%
Bauxite	kg	0.00	0.00	0.00	0.00	0.00	51%
NaCl	kg	0.01	0.00	0.01	0.00	0.01	0%
Sulphur	kg	0.00	0.00	0.00	0.00	0.00	0%
Clay	kg	0.00	6.86	6.86	6.86	0.00	100%
Sand	kg	0.03	0.00	0.03	0.00	0.03	0%
Water consumed	kg	25.29	3.08	28.38	2.42	25.96	9%
ENERGY							
Feedstock	MJ	0.04	0.00	0.04	0.00	0.04	0%
Processing: renewable	MJ	0.23	2.19	2.41	1.96	0.45	81%
Processing: non-renewable	MJ	2.39	84.46	86.85	51.33	35.53	59%
Transport	MJ	0.17	3.82	3.99	4.09	-0.10	102%
Total energy	MJ	2.82	90.47	93.30	57.38	35.92	62%
EMISSIONS TO AIR							
CO2	mg	2 090 378	9 916 743	12 007 121	9 067 061	2 940 060	76%
CO	mg	328	18 356	18 684	17 250	1 433	92%
CH4	mg	5	46	51	41	10	81%
General HC	mg	130	3 719	3 849	2 824	1 024	73%
NOx	mg	5 482	45 623	51 105	35 495	15 610	69%
SO2	mg	844	12 000	12 844	9 156	3 688	71%
NH3	mg	0	0	0	0	0	47%
Dust	mg	104	2 354	2 459	2 145	314	87%
HCl	mg	18	14	32	84	-52	263%
HF	mg	0.5	0.0	0.5	2.6	-2.0	476%
HBr	mg	0.0	0.0	0.0	0.0	0.0	0%
Metals (total)	mg	10.95	3.12	14.08	8.42	5.66	60%
Sb	mg	0.25	0.02	0.27	0.26	0.01	96%
As	mg	0.25	0.08	0.33	0.09	0.24	27%
Pb	mg	2.50	0.59	3.09	2.79	0.29	90%
Cr	mg	1.00	0.07	1.07	0.24	0.84	22%
Co	mg	0.50	0.01	0.51	0.10	0.40	20%
Cu	mg	3.00	0.09	3.09	0.64	2.44	21%
Mn	mg	1.25	0.19	1.44	0.35	1.10	24%
Ni	mg	0.25	0.24	0.49	0.17	0.32	35%
V	mg	0.25	0.72	0.97	0.41	0.56	43%
Sn	mg	0.50	0.06	0.56	0.13	0.43	23%
Hg	mg	1.00	0.31	1.31	2.65	-1.34	202%
Cd	mg	0.20	0.01	0.21	0.20	0.00	98%
Dioxins	μg	0.00030	0.00112	0.00142	0.00424	-0.00283	299%
EMISSIONS TO WATER							
Volume		24.02	1.51	25.53	0.78	24.75	3%
COD	litres	0.11	8.76	8.86	5.15	3.72	58%
BOD	mg	0.04	4.27	4.32	2.48	1.84	57%
Acid	mg	0.12	24.40	24.51	13.76	10.75	56%
Nitrates	mg	0.05	1.26	1.31	0.86	0.45	65%
Sulphates	mg	0.05	0.40	0.45	0.36	0.10	79%
Metals	mg	0.02	4.09	4.11	2.31	1.80	56%
Ammonium	mg	0.10	1.68	1.78	1.24	0.54	69%
Cl	mg	0.05	8.16	8.21	4.61	3.60	56%
Suspended solids	mg	0.27	104.89	105.17	55.99	49.17	53%
Hydrocarbons	mg	0.82	19.64	20.46	13.51	6.94	66%
Other N	mg	0.00	0.81	0.82	0.46	0.36	56%
Total DS	mg	48.84	481.61	530.44	417.81	112.63	79%
Br	mg	0.00	0.00	0.00	0.00	0.00	0%
F	mg	0.0001	0.0000	0.0001	0.0000	0.0001	0%
Sb	mg	0.0000	0.0000	0.0000	0.0000	0.0000	0%
As	mg	0.000001	0.000000	0.000001	0.000000	0.000001	0%
Pb	mg	0.000010	0.000000	0.000010	0.000000	0.000010	0%
Cr	mg	0.000004	0.000000	0.000004	0.000000	0.000004	0%
Co	mg	0.000002	0.000000	0.000002	0.000000	0.000002	0%
Cu	mg	0.000012	0.000000	0.000012	0.000000	0.000012	0%
Mn	mg	0.000005	0.000000	0.000005	0.000000	0.000005	0%
Ni	mg	0.000001	0.000000	0.000001	0.000000	0.000001	0%
V	mg	0.000001	0.000000	0.000001	0.000000	0.000001	0%
Sn	mg	0.000002	0.000000	0.000002	0.000000	0.000002	0%
Hg	mg	0.000000	0.000000	0.000000	0.000000	0.000000	0%
Cd	mg	0.000001	0.000000	0.000001	0.000000	0.000001	0%
SOLID WASTES							
Inert inorganic	mg	22	692 373	692 395	350 190	342 205	51%
Other industrial	mg	16 278	1 637 689	1 653 967	1 630 322	23 645	99%

Waste variants

The comparison of incineration and SLF above is based on the typical SLF composition shown in Table 3.1. A number of other cases are also considered, with various compositions. These cases are analysed for two reasons. Firstly, the environmental costs and benefits of recycling various solvent materials are examined. Secondly, the impacts of other factors, such as sulphur content, are also considered. In practice, there is some inter-relationship between the different components in a cement kiln and this affects emissions. However, this applies to the total loading in the kiln, not to the individual small parts of fuel load considered in the LCI. The interaction between components is therefore not modelled and comments on their influence are given elsewhere.

A wet process cement kiln is the basis of these comparisons.

Hydrocarbon waste

The hydrocarbon-based waste is taken to consist of toluene with other components. A high sulphur level of 2.5 percent is included. This waste is an example of a high calorific value waste. Other composition details are given on Table 3.1; the metal content is taken as being low.

Life Cycle Inventory results are presented in Table 3.9. For System III, the impacts of reprocessing and disposal of residue to incineration are shown. The environmental burdens associated with the production of new toluene are shown as negative because they are avoided if recycled toluene is used instead. The negative figure is the difference between the burdens of systems with and without recycling. A solvent recovery of 65 percent is used in the calculation. The cement kiln using coal and petcoke is included in System III and System I, incineration, as in the other comparisons.

The results show a consistent environmental advantage of recycling over incineration. In several instances, however, the benefits of using SLF are higher than those of recycling. This is due to the displacement of other cement kiln fuels compared to the relatively small burdens of producing new toluene to replace that recycled. In addition, many of the atmospheric pollutants in the recycling case arise from incineration of the residues, and for non-hydrocarbon materials are essentially the same as those from incineration of the total waste. Figure 3.8 shows the relationship in graphical form.

The results would be similar for recovery of general solvents – thinners – which can be taken as replacing white spirits or other petroleum cuts.

Table 3.9 Life Cycle Inventory data: incineration system, SLF to wet process cement kiln, recycling (toluene)

All data expressed per kg waste		SYSTEM I INCINERATION	SYSTEM II CEMENT KILN	SYSTEM III SOLVENT RECYCLING				DIFFERENCES	
	Units	Total	Cement Kiln With SLF	Reprocessing	New Material	Cement Kiln No SLF	Total	System I minus System II	System I minus System III
MATERIALS									
Coal	kg	1.46	0.48	0.04	-0.09	1.40	1.34	0.97	0.11
Oil	kg	0.83	0.26	0.01	-0.58	0.82	0.25	0.57	0.58
Gas	kg	0.04	0.03	0.01	-0.59	0.03	-0.55	0.01	0.60
Iron ore	kg	0.08	0.08	0.00	0.00	0.08	0.08	0.00	0.00
Limestone	kg	7.10	7.09	0.00	-0.01	7.09	7.08	0.01	0.01
Bauxite	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NaCl	kg	0.06	0.00	0.06	-0.02	0.00	0.04	0.06	0.02
Sulphur	kg	0.00	0.00	0.00	-0.01	0.00	-0.01	0.00	0.01
Clay	kg	3.04	3.04	0.00	0.00	3.04	3.04	0.00	0.00
Sand	kg	0.03	0.00	0.01	-0.61	0.00	-0.60	0.03	0.63
Water consumed	kg	34.26	7.82	9.38	-0.04	8.82	18.17	26.43	16.09
ENERGY									
Feedstock	MJ	0.16	0.00	0.16	-25.16	0.00	-25.00	0.16	25.16
Processing: renewable	MJ	1.36	0.93	0.16	-0.44	1.09	0.80	0.43	0.56
Processing: non-renewable	MJ	76.52	25.29	4.90	-17.24	73.32	60.98	51.23	15.54
Transport	MJ	1.91	1.97	0.40	-0.01	1.72	2.11	-0.07	-0.20
Total energy	MJ	79.94	28.19	5.61	-42.85	76.12	38.88	51.75	41.05
EMISSIONS TO AIR									
CO2	mg	12 416 165	8 094 666	1 161 845	-1 272 999	9 250 213	9 139 059	4 321 498	3 277 105
CO	mg	17 785	15 765	324	- 606	17 319	17 037	2 020	748
CH4	mg	29	20	3	- 8	23	18	9	11
General HC	mg	2 879	1 384	576	- 6 460	2 715	- 3 169	1 494	6 048
NOx	mg	98 705	55 823	4 811	- 5 509	62 498	51 800	42 882	36 905
SO2	mg	31 955	24 617	2 105	- 5 460	30 134	26 779	7 338	5 177
NH3	mg	-0.19	-0.04	0.54	-6.68	-0.20	-6.35	0	6
Dust	mg	2 108	1 690	107	- 630	1 960	1 436	417	671
HCl	mg	26	9	12	- 7	14	19	17	7
HF	mg	0.54	2.57	0.00	-0.56	0.04	-0.52	-2.0	1.1
HBr	mg	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0
Metals (total)	mg	9.58	2.44	0.00	-0.03	3.12	3.10	7.13	6.48
Sb	mg	0.27	0.25	0.00	0.00	0.02	0.02	0.02	0.25
As	mg	0.33	0.07	0.00	0.00	0.08	0.08	0.26	0.25
Pb	mg	0.59	0.15	0.00	0.00	0.59	0.59	0.44	0.00
Cr	mg	0.07	0.02	0.00	0.00	0.07	0.07	0.05	0.00
Co	mg	0.51	0.10	0.00	0.00	0.01	0.01	0.41	0.50
Cu	mg	3.09	0.62	0.00	0.00	0.09	0.09	2.46	3.00
Mn	mg	1.44	0.30	0.00	0.00	0.19	0.19	1.14	1.25
Ni	mg	0.49	0.11	0.00	0.00	0.24	0.24	0.38	0.25
V	mg	0.97	0.23	0.00	0.00	0.72	0.72	0.74	0.25
Sn	mg	0.56	0.12	0.00	0.00	0.06	0.06	0.45	0.50
Hg	mg	0.31	0.08	0.00	0.00	0.31	0.31	0.23	0.00
Cd	mg	0.21	0.20	0.00	0.00	0.01	0.01	0.00	0.20
Dioxins	µg	0.00494	0.00423	0.00010	0.00000	0.00447	0.00456	0.00	0.00
EMISSIONS TO WATER									
Volume	litres	25.57	0.39	8.81	-1.52	1.49	8.78	25.18	16.79
COD	mg	8.12	2.56	0.42	-2.15	7.98	6.25	5.56	1.87
BOD	mg	3.99	1.24	0.20	-2.10	3.94	2.04	2.76	1.95
Acid	mg	23.16	6.90	1.09	-4.74	23.02	19.36	16.26	3.80
Nitrates	mg	1.06	0.42	0.08	-0.88	0.99	0.19	0.64	0.87
Sulphates	mg	0.31	0.17	0.09	-0.73	0.20	-0.44	0.14	0.75
Metals	mg	3.88	1.16	0.18	-17.63	3.86	-13.60	2.73	17.48
Ammonium	mg	1.33	0.60	0.11	-0.95	1.20	0.36	0.73	0.97
Cl	mg	7.74	2.31	0.37	-2.02	7.68	6.03	5.43	1.71
Suspended solids	mg	102.40	28.17	4.65	-18.59	102.03	88.09	74.24	14.32
Hydrocarbons	mg	16.47	6.62	3.78	-14.51	15.35	4.62	9.85	11.85
Other N	mg	0.77	0.23	0.04	-0.79	0.77	0.01	0.54	0.76
Total DS	mg	322.79	198.18	43.27	-11637.25	255.72	-11338.26	124.61	11661.05
Br	mg	0.0001	0.0000	0.0000	-0.0001	0.0000	-0.0001	0.00	0.00
F	mg	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001
Sb	mg	0.000001	0.000000	0.000000	-0.000001	0.000000	-0.000001	0.0000	0.0000
As	mg	0.000001	0.000000	0.000000	-0.000001	0.000000	-0.000001	0.000001	0.000002
Pb	mg	0.000000	0.000000	0.000000	-0.000001	0.000000	-0.000001	0.000000	0.000001
Cr	mg	0.000000	0.000000	0.000000	-0.000001	0.000000	-0.000001	0.000000	0.000001
Co	mg	0.000002	0.000000	0.000000	0.000000	0.000000	0.000000	0.000002	0.000002
Cu	mg	0.000012	0.000000	0.000000	-0.000001	0.000000	-0.000001	0.000012	0.000013
Mn	mg	0.000005	0.000000	0.000000	-0.000001	0.000000	-0.000001	0.000005	0.000006
Ni	mg	0.000001	0.000000	0.000000	-0.000001	0.000000	-0.000001	0.000001	0.000002
V	mg	0.000001	0.000000	0.000000	-0.000001	0.000000	-0.000001	0.000001	0.000002
Sn	mg	0.000002	0.000000	0.000000	-0.000001	0.000000	-0.000001	0.000002	0.000003
Hg	mg	0.000000	0.000000	0.000000	-0.000001	0.000000	-0.000001	0.000000	0.000001
Cd	mg	0.000001	0.000000	0.000000	-0.000001	0.000000	-0.000001	0.000001	0.000002
SOLID WASTES									
Inert inorganic	mg	692 196	176 622	337	- 5 191	692 157	686 302	515 574	5 894
Other industrial	mg	752 013	724 155	16 826	- 15 334	729 266	730 759	27 858	21 255

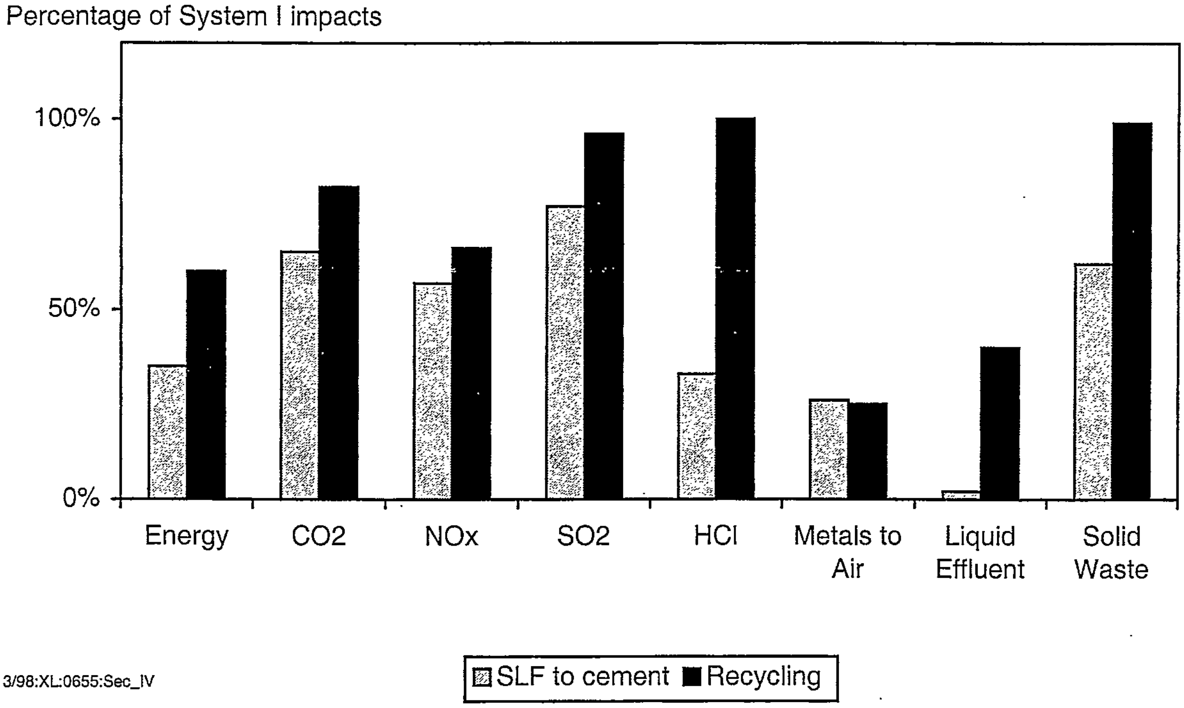

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Figure 3.8 Impacts as percentage of incineration impacts: hydrocarbon solvent

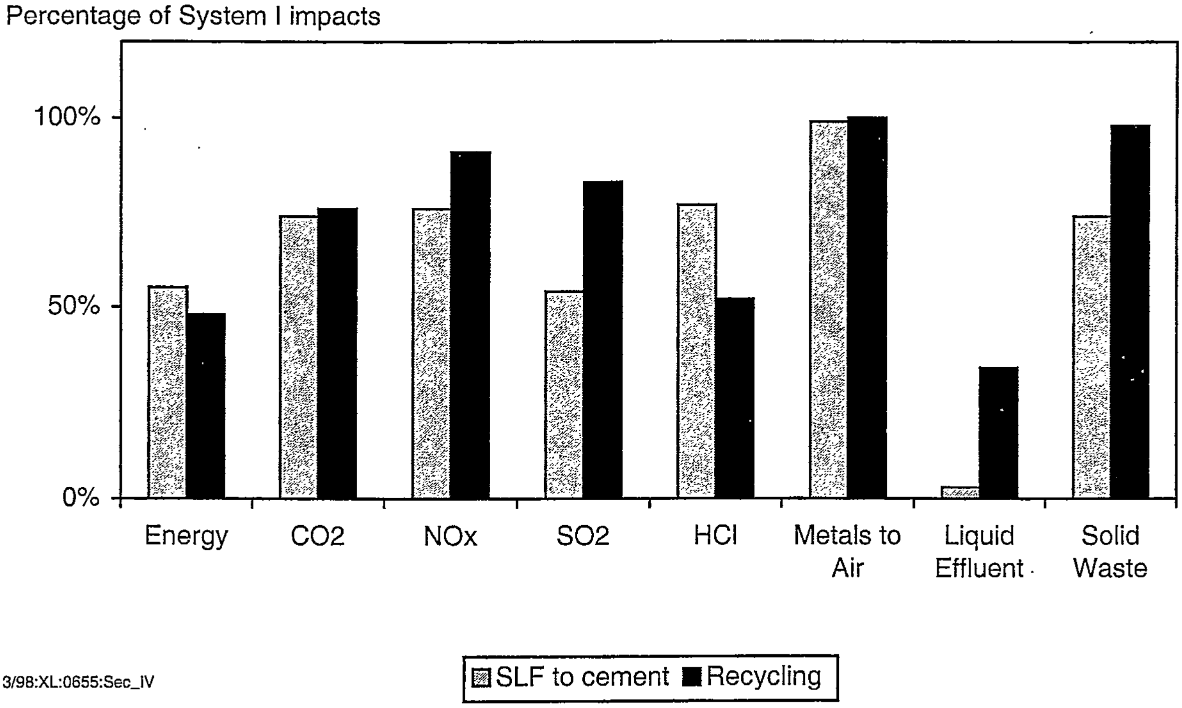

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Figure 3.9 Impacts as percentage of incineration impacts: oxygenated solvent

Table 3.10 Life Cycle Inventory data: incineration system, SLF to wet process cement kiln, recycling (acetone)

All data expressed per kg waste		SYSTEM I INCINERATION	SYSTEM II CEMENT KILN	SYSTEM III SOLVENT RECYCLING				DIFFERENCES	
	Units	Total	Cement Kiln With SLF	Reprocessing	New Material	Cement Kiln No SLF	Total	System I minus System II	System I minus System III
MATERIALS									
Coal	kg	1.44	0.77	0.02	-0.09	1.40	1.33	0.67	0.11
Oil	kg	0.83	0.43	0.01	-0.58	0.82	0.25	0.40	0.58
Gas	kg	0.04	0.03	0.00	-0.59	0.03	-0.56	0.01	0.60
Iron ore	kg	0.08	0.08	0.00	0.00	0.08	0.08	0.00	0.00
Limestone	kg	7.10	7.09	0.00	-0.01	7.09	7.08	0.01	0.01
Bauxite	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NaCl	kg	0.00	0.00	0.00	-0.02	0.00	-0.01	0.00	0.02
Sulphur	kg	0.00	0.00	0.00	-0.01	0.00	-0.01	0.00	0.01
Clay	kg	3.04	3.04	0.00	0.00	3.04	3.04	0.00	0.00
Sand	kg	0.03	0.00	0.01	-0.61	0.00	-0.60	0.03	0.63
Water consumed	kg	34.08	8.13	9.21	-0.04	8.82	17.99	25.95	16.09
ENERGY									
Feedstock	MJ	0.01	0.00	0.01	-25.16	0.00	-25.15	0.01	25.16
Processing: renewable	MJ	1.30	1.01	0.10	-0.44	1.09	0.74	0.29	0.56
Processing: non-renewable	MJ	75.51	40.35	3.90	-17.24	73.32	59.97	35.17	15.54
Transport	MJ	1.88	1.98	0.38	-0.01	1.72	2.08	-0.10	-0.20
Total energy	MJ	78.70	43.34	4.38	-42.85	76.12	37.65	35.36	41.05
EMISSIONS TO AIR									
CO2	mg	11 279 725	8 299 579	542 135	-1 272 999	9 250 213	8 519 349	2 980 146	2 760 376
CO	mg	17 633	15 942	224	- 606	17 319	16 936	1 690	696
CH4	mg	27	21	2	- 8	23	17	6.24	10.77
General HC	mg	2 836	1 836	534	- 6 460	2 715	- 3 211	1000.26	6047.63
NOx	mg	68 000	51 385	4 687	- 5 509	62 498	61 676	16 615	6 324
SO2	mg	30 775	16 637	925	- 5 460	30 134	25 599	14 138	5 176
NH3	mg	-0.20	-0.09	0.52	-6.68	-0.20	-6.36	-0.11	6.15
Dust	mg	2 062	1 762	79	- 630	1 960	1 409	300.09	652.99
HCl	mg	15	12	1.52	-7.39	14	8	4	7
HF	mg	0.54	2.58	0.53	-0.56	0.04	0.00	-2.040	0.538
HBr	mg	0.00	0.00	0.51	0.00	0.00	0.51	0.00	-0.51
Metals (total)	mg	17.58	17.43	14.45	-0.03	3.12	17.55	0.14	0.03
Sb	mg	0.27	0.26	0.25	0.00	0.02	0.27	0.01	0.00
As	mg	0.33	0.09	0.25	0.00	0.08	0.33	0.24	0.00
Pb	mg	2.09	1.78	1.50	0.00	0.59	2.09	0.31	0.00
Cr	mg	1.57	0.33	1.50	0.00	0.07	1.57	1.24	0.00
Co	mg	0.51	0.10	0.50	0.00	0.01	0.51	0.40	0.00
Cu	mg	3.09	0.64	3.00	0.00	0.09	3.09	2.45	0.00
Mn	mg	1.44	0.34	1.25	0.00	0.19	1.44	1.10	0.00
Ni	mg	0.49	0.17	0.25	0.00	0.24	0.49	0.33	0.00
V	mg	0.97	0.40	0.25	0.00	0.72	0.97	0.57	0.00
Sn	mg	0.56	0.13	0.50	0.00	0.06	0.56	0.43	0.00
Hg	mg	5.31	12.63	5.00	0.00	0.31	5.31	-7.31	0.00
Cd	mg	0.21	0.20	0.20	0.00	0.01	0.21	0.00	0.00
Dioxins	μg	0.00477	0.00421	0.00004	0.00000	0.00447	0.00451	0.00056	0.00027
EMISSIONS TO WATER									
Volume	litres	25.50	0.73	8.74	-1.52	1.49	8.71	24.77	16.79
COD	mg	8.08	4.26	0.38	-2.15	7.98	6.21	3.82	1.87
BOD	mg	3.98	2.08	0.19	-2.10	3.94	2.03	1.89	1.95
Acid	mg	23.13	11.93	1.05	-4.74	23.02	19.33	11.20	3.80
Nitrates	mg	1.03	0.60	0.06	-0.88	0.99	0.17	0.43	0.87
Sulphates	mg	0.24	0.18	0.02	-0.73	0.20	-0.51	0.06	0.75
Metals	mg	3.88	2.00	0.17	-17.63	3.86	-13.60	1.88	17.48
Ammonium	mg	1.29	0.80	0.07	-0.95	1.20	0.32	0.49	0.97
Cl	mg	7.72	3.99	0.35	-2.02	7.68	6.01	3.74	1.71
Suspended solids	mg	102.27	51.05	4.52	-18.59	102.03	87.95	51.22	14.32
Hydrocarbons	mg	16.09	9.45	3.40	-14.51	15.35	4.24	6.64	11.85
Other N	mg	0.77	0.40	0.04	-0.79	0.77	0.01	0.37	0.76
Total DS	mg	300.16	221.38	20.68	-11637.25	255.72	-11360.85	78.7805	11661.0049
Br	mg	0.0001	0.0000	0.0001	-0.0001	0.0000	0.0000	0.0001	0.0001
F	mg	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.000050	0.000033
Sb	mg	0.000001	0.000000	0.000001	-0.000001	0.000000	0.000000	0.000001	0.000001
As	mg	0.000001	0.000000	0.000001	-0.000001	0.000000	0.000000	0.000001	0.000001
Pb	mg	0.000006	0.000000	0.000006	-0.000001	0.000000	0.000005	0.000006	0.000001
Cr	mg	0.000006	0.000000	0.000006	-0.000001	0.000000	0.000005	0.000006	0.000001
Co	mg	0.000002	0.000000	0.000002	0.000000	0.000000	0.000002	0.000002	0.000000
Cu	mg	0.000012	0.000000	0.000012	-0.000001	0.000000	0.000011	0.000012	0.000001
Mn	mg	0.000005	0.000000	0.000005	-0.000001	0.000000	0.000004	0.000005	0.000001
Ni	mg	0.000001	0.000000	0.000001	-0.000001	0.000000	0.000000	0.000001	0.000001
V	mg	0.000001	0.000000	0.000001	-0.000001	0.000000	0.000000	0.000001	0.000001
Sn	mg	0.000002	0.000000	0.000002	-0.000001	0.000000	0.000001	0.000002	0.000001
Hg	mg	0.000001	0.000000	0.000001	-0.000001	0.000000	0.000000	0.000001	0.000001
Cd	mg	0.000001	0.000000	0.000001	-0.000001	0.000000	-0.000001	0.000001	0.000001
SOLID WASTES									
Inert inorganic	mg	692 174	335 217	315	- 6 191	692 157	686 281	356 958	5 894
Other industrial	mg	739 602	726 574	6 589	- 15 334	729 266	720 521	13 027	19 081

The waste examined has a fairly high sulphur content of 2.5 percent. A sensitivity analysis using Chem Systems' computer model suggests that SO_2 emissions will be worse in the SLF case for sulphur contents in excess of around 3.5 percent. This confirms the obvious: emissions of SO_2 will increase if SLF contains more sulphur per MJ than the other fuels, after allowing for differences in retention between cement kilns and incinerators.

Oxygenated waste

Acetone is the main component of the hypothetical waste taken as an example of oxygenated solvents. Relatively high metal contents, of chromium, lead, and mercury are also included.

The methodology is the same as for the hydrocarbon waste, and the results are given in Table 3.10 and Figure 3.9. Recycling shows a benefit over incineration. As with toluene, the net avoided burdens from recycling are broadly comparable to those avoided by displacing coke and petcoke in the cement kiln.

Chlorinated waste

A very highly chlorinated material is the next hypothetical waste considered. It is taken as being largely trichloroethylene, with a high solids content (see Table 3.1).

Several different factors affect the burdens in the different disposal routes. In the incinerator, the high chlorine content of the waste results in a high consumption of lime per unit waste, with associated production burdens. In addition, supplementary fuel (or other waste) is required to make up the calorific value.

In the cement kiln, the low calorific value of the waste means that it displaces smaller quantities of coal and petcoke than in the cases reviewed above.

The inventory is presented in Table 3.11, and selected burdens are compared on Figure 3.10. The net benefits of avoided burdens from incineration and from burning conventional cement kiln fuels are broadly comparable. The big exception is in the emissions of HCl. Here, the SLF to cement kiln route is worse than incineration by a factor of around five, reflecting the very high scrubbing efficiency in the incinerator. Figure 3.10 is limited to 200 percent (a factor of two) for reasons of presentation. The inventory does not show a corresponding increase in dioxins from the cement kiln because the relationship between chlorine content and dioxin levels is not established; dioxin quantities are calculated on the basis of flue gas volume. The HCl emissions are reduced in the recycling route because most of the chlorine is retained as part of the recycled trichloroethylene.

Table 3.11 Life Cycle Inventory data: incineration system, SLF to wet process cement kiln, recycling (trichloroethylene)

All data expressed per kg waste	Units	SYSTEM I INCINERATION	SYSTEM II CEMENT KILN	SYSTEM III SOLVENT RECYCLING				DIFFERENCES	
		Total	Cement Kiln With SLF	Reprocessing	New Material	Cement Kiln No SLF	Total	System I minus System II	System I minus System III
MATERIALS									
Coal	kg	1.48	1.12	0.04	-0.17	1.40	1.27	0.36	0.21
Oil	kg	0.99	0.65	0.01	-0.08	0.82	0.75	0.35	0.24
Gas	kg	0.10	0.03	0.01	-0.11	0.03	-0.07	0.06	0.16
Iron ore	kg	0.08	0.08	0.00	0.00	0.08	0.08	0.00	0.00
Limestone	kg	7.10	7.09	0.00	0.00	7.09	7.09	0.01	0.00
Bauxite	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NaCl	kg	0.07	0.00	0.00	-0.44	0.00	-0.44	0.07	0.51
Sulphur	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Clay	kg	3.04	3.04	0.00	0.00	3.04	3.04	0.00	0.00
Sand	kg	0.03	0.00	0.01	0.00	0.00	0.01	0.03	0.02
Water consumed	kg	34.48	8.50	9.22	-1.55	8.82	16.49	25.98	17.99
ENERGY									
Feedstock	MJ	0.19	0.00	0.01	-5.70	0.00	-5.69	0.19	5.87
Processing: renewable	MJ	1.45	1.10	0.20	-0.59	1.09	0.69	0.36	0.76
Processing: non-renewable	MJ	86.49	58.55	4.97	-10.45	73.32	67.84	27.95	18.65
Transport	MJ	2.02	2.00	0.38	-0.18	1.72	1.92	0.02	0.09
Total energy	MJ	90.15	61.64	5.55	-16.91	76.12	64.76	28.51	25.38
EMISSIONS TO AIR									
CO2	mg	11 518 071	8 475 758	764 780	- 377 215	9 250 213	9 637 777	3 042 313	1 880 294
CO	mg	17 855	16 014	274	- 400	17 319	17 193	1 841	662
CH4	mg	31	23	4	- 12	23	15	7.58	15.90
General HC	mg	4 255	2 382	571	- 1 148	2 715	2 139	1872.95	2116.61
NOx	mg	74 477	56 105	4 837	- 1 571	62 498	65 763	18 372	8 713
SO2	mg	32 571	24 360	1 202	- 2 358	30 134	28 977	8 210	3 593
NH3	mg	2.69	-0.15	0.52	-0.08	-0.20	0.24	2.84	2.45
Dust	mg	2 151	1 827	97	- 278	1 960	1 779	323.88	371.99
HCl	mg	680.48	3269.99	10.95	-4.41	13.89	20.44	-2589.51	660.04
HF	mg	0.54	2.59	0.53	-0.12	0.04	0.44	-2.050	0.101
HBr	mg	0.34	0.00	0.51	0.00	0.00	0.51	0.34	-0.17
Metals (total)	mg	17.65	18.30	14.45	-0.88	3.12	16.69	-0.65	0.96
Sb	mg	0.27	0.27	0.25	0.00	0.02	0.27	0.01	0.00
As	mg	0.33	0.11	0.25	0.00	0.08	0.33	0.22	0.00
Pb	mg	2.09	1.94	1.50	0.00	0.59	2.09	0.14	0.00
Cr	mg	1.57	0.35	1.50	0.00	0.07	1.57	1.22	0.00
Co	mg	0.51	0.11	0.50	0.00	0.01	0.51	0.40	0.00
Cu	mg	3.09	0.66	3.00	0.00	0.09	3.09	2.42	0.00
Mn	mg	1.44	0.40	1.25	0.00	0.19	1.44	1.05	0.00
Ni	mg	0.49	0.24	0.25	0.00	0.24	0.49	0.26	0.00
V	mg	1.05	0.60	0.25	0.00	0.72	0.97	0.45	0.08
Sn	mg	0.56	0.15	0.50	0.00	0.06	0.56	0.41	0.00
Hg	mg	5.31	12.71	5.00	0.00	0.31	5.31	-7.40	0.00
Cd	mg	0.21	0.20	0.20	0.00	0.01	0.21	0.00	0.00
Dioxins	μg	0.00485	0.00412	0.00004	-0.00001	0.00447	0.00450	0.00073	0.00035
EMISSIONS TO WATER									
Volume	litres	25.72	1.14	8.75	-0.75	1.49	9.49	24.58	16.23
COD	mg	9.69	6.31	0.41	-24.42	7.98	-16.03	3.37	25.72
BOD	mg	4.77	3.10	0.20	-4.93	3.94	-0.80	1.67	5.57
Acid	mg	27.78	18.01	1.06	-7.35	23.02	16.72	9.77	11.06
Nitrates	mg	1.23	0.82	0.08	-0.20	0.99	0.87	0.41	0.36
Sulphates	mg	0.27	0.20	0.04	-0.17	0.20	0.06	0.08	0.21
Metals	mg	4.62	3.02	0.17	-37.07	3.86	-33.04	1.60	37.66
Ammonium	mg	1.52	1.03	0.12	-0.38	1.20	0.93	0.49	0.59
Cl	mg	9.75	6.01	0.36	-6.08	7.68	1.97	3.74	7.78
Suspended solids	mg	114.93	78.69	4.57	-24.79	102.03	81.81	36.24	33.12
Hydrocarbons	mg	23.14	12.86	3.76	-27.41	15.35	-8.30	10.27	31.43
Other N	mg	0.93	0.60	0.04	-1.21	0.77	-0.41	0.33	1.33
Total DS	mg	346.37	249.40	41.72	-251.91	255.72	45.53	96.9617	300.8344
Br	mg	0.0001	0.0000	0.0001	-0.0001	0.0000	0.0000	0.0001	0.0001
F	mg	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.000050	0.000033
Sb	mg	0.000001	0.000000	0.000001	-0.000001	0.000000	0.000000	0.000001	0.000001
As	mg	0.000001	0.000000	0.000001	-0.000001	0.000000	0.000000	0.000001	0.000001
Pb	mg	0.000006	0.000000	0.000006	-0.000001	0.000000	0.000005	0.000006	0.000001
Cr	mg	0.000006	0.000000	0.000006	-0.000001	0.000000	0.000005	0.000006	0.000001
Co	mg	0.000002	0.000000	0.000002	0.000000	0.000000	0.000002	0.000002	0.000000
Cu	mg	0.000012	0.000000	0.000012	-0.000001	0.000000	0.000011	0.000012	0.000001
Mn	mg	0.000005	0.000000	0.000005	-0.000001	0.000000	0.000004	0.000005	0.000001
Ni	mg	0.000001	0.000000	0.000001	-0.000001	0.000000	0.000000	0.000001	0.000001
V	mg	0.000001	0.000000	0.000001	-0.000001	0.000000	0.000000	0.000001	0.000002
Sn	mg	0.000002	0.000000	0.000002	-0.000001	0.000000	0.000001	0.000002	0.000001
Hg	mg	0.000001	0.000000	0.000001	-0.000001	0.000000	0.000000	0.000001	0.000001
Cd	mg	0.000001	0.000000	0.000001	-0.000001	0.000000	-0.000001	0.000001	0.000001
SOLID WASTES									
Inert inorganic	mg	693 115	526 876	318	- 26 557	692 157	665 918	166 239	27 197
Other industrial	mg	910 106	729 498	12 172	- 32 451	729 266	708 988	180 608	201 118

Aqueous waste

The next hypothetical waste shown in Table 3.1 is one containing a very high proportion of water, around 90 percent. The organic material is taken to be methanol, but it would not be economically worthwhile to recover this relatively low value material from such a dilute solution. Only incineration and SLF to cement kilns are considered for this aqueous waste.

The LHV is actually slightly negative because of the energy needed to evaporate the water and allowance is made for heating it. In the SLF to cement kiln case (System II), some additional coal and petcoke are needed. The picture presented by the LCI data and Figure 3.11 is mixed. The advantages of the SLF route are marginal or negative for several variables. While in incineration, an average "burn menu" calorific value is assumed, for cement kilns the requirements, as indicated by operators, are not as clear. The lack of attractiveness of the cement kiln for disposal of aqueous wastes might therefore be understated.

3.12 Life Cycle Inventory data: incineration system and SLF to cement kiln: aqueous waste

All data expressed per kg waste	Units	SYSTEM I INCINERATION			SYSTEM II CEMENT KILN	DIFFERENCES	
		Incineration With SLF	Cement Kiln No SLF	Total	Cement Kiln With SLF	System I minus System II	System II as % System I
MATERIALS							
Coal	kg	0.04	1.40	1.44	1.49	-0.05	104%
Oil	kg	0.47	0.82	1.30	0.88	0.42	68%
Gas	kg	0.01	0.03	0.04	0.04	0.00	91%
Iron ore	kg	0.00	0.08	0.08	0.08	0.00	100%
Limestone	kg	0.01	7.09	7.10	7.09	0.01	100%
Bauxite	kg	0.00	0.00	0.00	0.00	0.00	106%
NaCl	kg	0.00	0.00	0.00	0.00	0.00	2%
Sulphur	kg	0.00	0.00	0.00	0.00	0.00	0%
Clay	kg	0.00	3.04	3.04	3.04	0.00	100%
Sand	kg	0.03	0.00	0.03	0.00	0.03	0%
Water consumed	kg	25.36	8.82	34.18	8.91	25.27	26%
ENERGY							
Feedstock	MJ	0.01	0.00	0.01	0.00	0.01	0%
Processing: renewable	MJ	0.22	1.09	1.30	1.19	0.11	92%
Processing: non-renewable	MJ	21.85	73.32	95.17	78.44	16.73	82%
Transport	MJ	0.17	1.72	1.88	2.01	-0.12	107%
Total energy	MJ	22.24	76.12	98.36	81.64	16.72	83%
EMISSIONS TO AIR							
CO2	mg	1 614 811	9 250 213	10 865 024	9792303.87	1072719.80	90%
CO	mg	274	17 319	17 592	18340.58	-748.09	104%
CH4	mg	5	23	27	25.09	2.33	92%
General HC	mg	123	2 715	2 838	2 979	-141.17	105%
NOx	mg	8 326	62 498	70 823	67 603	3220.57	95%
SO2	mg	683	30 134	30 817	32 802	-1984.96	106%
NH3	mg	9	0	8	0	8.58	-2%
Dust	mg	92	1 960	2 052	2 110	-57.71	103%
HCl	mg	1.90	14	16	20	- 4	126%
HF	mg	0.51	0.04	0.54	3	- 2	480%
HBr	mg	0.00	0.00	0.00	0	0	
Metals (total)	mg	6.67	3.12	9.79	5	5	51%
Sb	mg	0.25	0.02	0.27	0.27	0	100%
As	mg	0.25	0.08	0.33	0.14	0	41%
Pb	mg	0.00	0.59	0.59	0.62	0	106%
Cr	mg	0.00	0.07	0.07	0.08	0	106%
Co	mg	0.50	0.01	0.51	0.11	0	21%
Cu	mg	3.00	0.09	3.09	0.69	2.40	22%
Mn	mg	1.25	0.19	1.44	0.46	0.99	32%
Ni	mg	0.25	0.24	0.49	0.31	0.18	63%
V	mg	0.46	0.72	1.18	0.82	0.37	69%
Sn	mg	0.50	0.06	0.56	0.16	0.40	29%
Hg	mg	0.00	0.31	0.31	0.33	-0.02	106%
Cd	mg	0.20	0.01	0.21	0.21	0.00	100%
Dioxins	μg	0.00092	0.00447	0.00538	0.00	0.00	88%
EMISSIONS TO WATER							
Volume	litres	24.01	1.49	25.50	1.59	23.91	6%
COD	mg	0.10	7.98	8.08	8.56	-0.48	106%
BOD	mg	0.04	3.94	3.98	4.22	-0.24	106%
Acid	mg	0.11	23.02	23.13	24.65	-1.52	107%
Nitrates	mg	0.05	0.99	1.04	1.06	-0.02779	103%
Sulphates	mg	0.04	0.20	0.24	0.22	0.02	90%
Metals	mg	0.02	3.86	3.88	4.14	-0.26	107%
Ammonium	mg	0.09	1.20	1.29	1.29	-0.01	100%
Cl	mg	0.04	7.68	7.72	8.23	-0.51	107%
Suspended solids	mg	0.25	102.03	102.27	108.91	-6.64	106%
Hydrocarbons	mg	0.75	15.35	16.10	16.60	-0.50	103%
Other N	mg	0.00	0.77	0.77	0.82	-0.05	107%
Total DS	mg	45.24	255.72	300.96	280.04	20.93	93%
Br	mg	0.0001	0.0000	0.0001	0.00	0.00	0%
F	mg	0.0001	0.0000	0.0001	0.00	0.00	0%
Sb	mg	0.000001	0.000000	0.000001	0.00	0.00	0%
As	mg	0.000001	0.000000	0.000001	0.0000	0.00	0%
Pb	mg	0.000000	0.000000	0.000000	0.0000	0.00	
Cr	mg	0.000000	0.000000	0.000000	0.000000	0.00	
Co	mg	0.000002	0.000000	0.000002	0.000000	0.00	0%
Cu	mg	0.000012	0.000000	0.000012	0.000000	0.00	0%
Mn	mg	0.000005	0.000000	0.000005	0.000000	0.0000	0%
Ni	mg	0.000001	0.000000	0.000001	0.000000	0.0000	0%
V	mg	0.000002	0.000000	0.000002	0.000000	0.000002	0%
Sn	mg	0.000002	0.000000	0.000002	0.000000	0.000002	0%
Hg	mg	0.000000	0.000000	0.000000	0.000000	0.000000	
Cd	mg	0.000001	0.000000	0.000001	0.000000	0.000001	0%
SOLID WASTES							
Inert inorganic	mg	19	692 157	692 175	736 357	- 44 182	106%
Other industrial	mg	10 214	729 266	739 480	732 694	6 787	99%

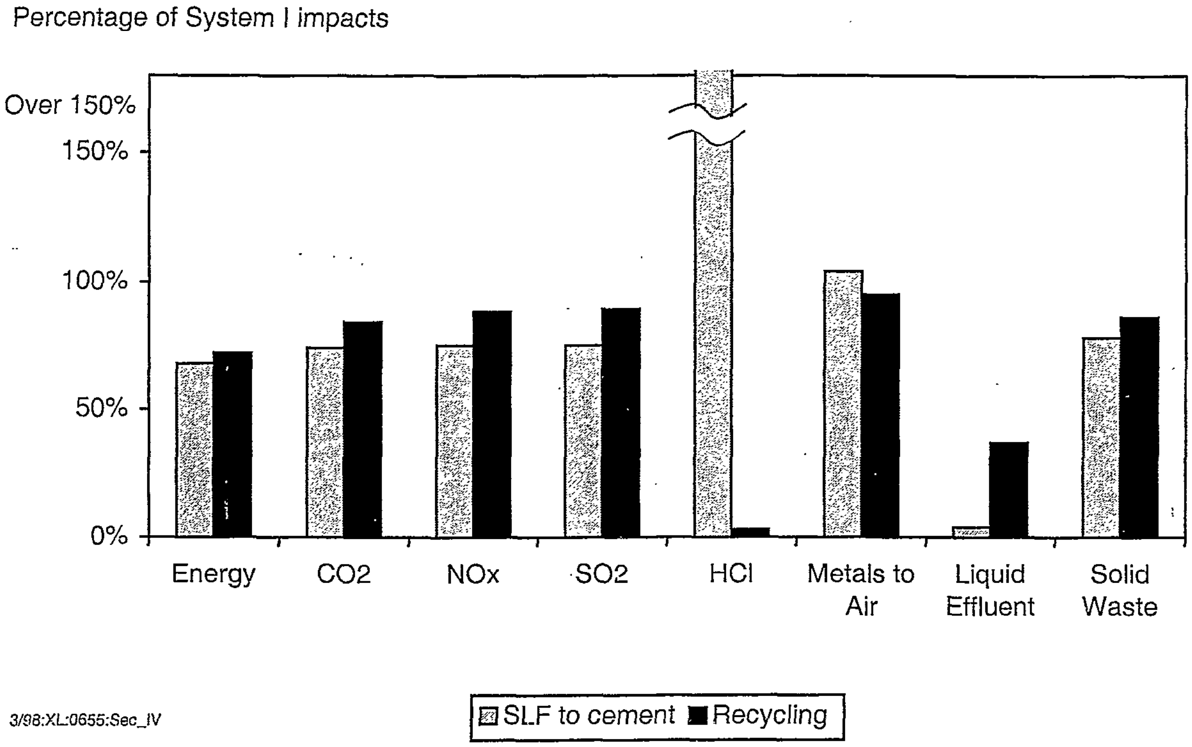


Figure 3.10 Impacts as percentage of incineration impacts: chlorinated waste

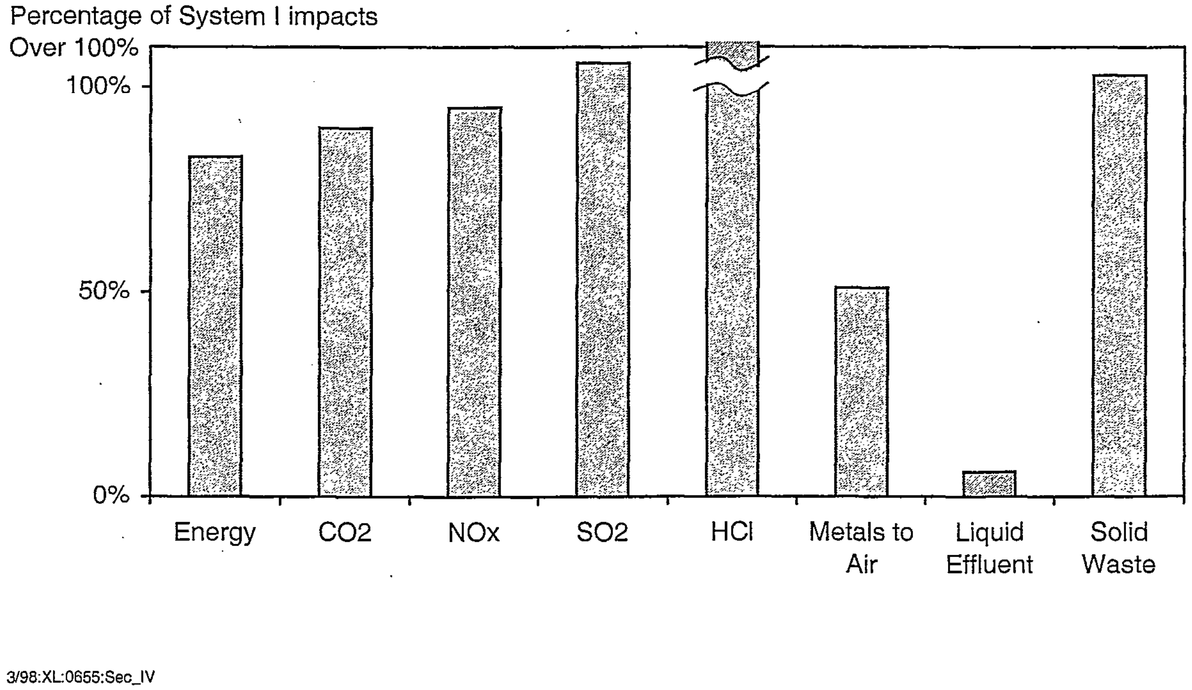


Figure 3.11 Impacts as percentage of incineration impacts: aqueous waste

Oily Wastes

The final hypothetical waste is an oily waste, similar to used lube oil. Table 3.13 shows the Life Cycle Inventory data. Two incinerations cases are shown:

- System IA, in which the waste oil is added as an additional feed to the incinerator, without replacing any other stream.
- System IB, in which the waste oil is used in circumstances where the incinerator would otherwise need to burn a supplementary fuel to achieve temperature conditions. In this case, the waste oil substitutes an equivalent quantity of gas oil.

  Systems IB represents a "best-case" example of lube oil being used as fuel. It is a best case because.

  - it omits any burdens from a reprocessing step
  - combustion of both waste and gas oil is under the higher controlled conditions of a hazardous waste incinerator rather than in a roadstone plant; this benefits the slightly "dirtier" waste oil.

As can be seen from Table 3.13 and Figure 3.12, the route of SLF to cement kilns shows environmental benefits even compared to System IB. SLF is used in German cement kilns. Other disposal routes are more economic in the UK.

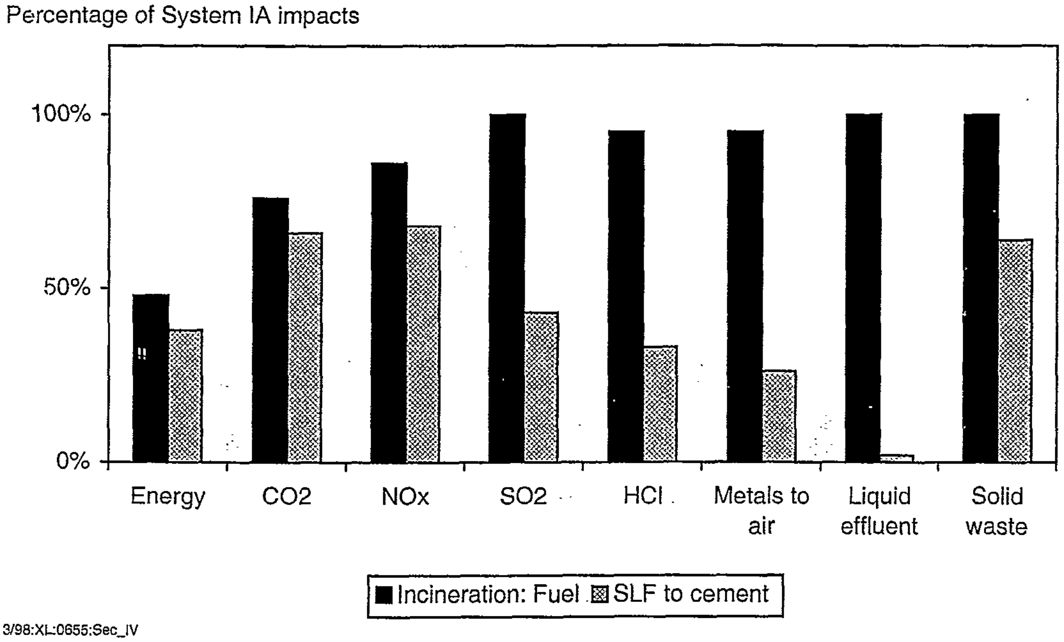


Figure 3.12 **Impacts as percentage of incineration impacts, no fuel substitution : oily waste**

Table 3.13 Life cycle Inventory data: incineration system and SLF to cement kiln: oily waste

All data expressed per kg waste		SYSTEM IA INCINERATION (NO FUEL SUBSTITUTION)	SYSTEM IB INCINERATION (FUEL SUBSTITUTION)	SYSTEM II CEMENT KILN	DIFFERENCES	
	Units	Total	Total	Cement Kiln With SLF	System IA minus System II	System IB minus System II
MATERIALS						
Coal	kg	1.44	1.44	0.52	0.92	0.92
Oil	kg	0.83	-0.15	0.28	0.55	-0.43
Gas	kg	0.04	0.04	0.03	0.01	0.01
Iron ore	kg	0.08	0.08	0.08	0.00	0.00
Limestone	kg	7.10	7.10	7.09	0.01	0.01
Bauxite	kg	0.00	0.00	0.00	0.00	0.00
NaCl	kg	0.01	0.01	0.00	0.01	0.01
Sulphur	kg	0.00	0.00	0.00	0.00	0.00
Clay	kg	3.04	3.04	3.04	0.00	0.00
Sand	kg	0.03	0.03	0.00	0.03	0.03
Water consumed	kg	34.11	33.91	7.86	26.25	26.05
ENERGY						
Feedstock	MJ	0.03	0.02	0.00	0.03	0.02
Processing: renewable	MJ	1.31	1.31	0.94	0.37	0.36
Processing: non-renewable	MJ	75.68	34.51	27.12	48.56	7.40
Transport	MJ	1.89	1.88	1.98	-0.09	-0.09
Total energy	MJ	78.91	37.72	30.03	48.87	7.69
EMISSIONS TO AIR						
CO2	mg	12 306 395	9 391 244	8 177 291	4 129 105	1 213 954
CO	mg	17 742	17 447	15 902	1 840	1 545
CH4	mg	28	27	20	8	8
General HC	mg	2 843	2 840	1 439	1 404	1 401
NOx	mg	69 009	59 470	47 099	21 909	12 371
SO2	mg	30 971	30 883	13 418	17 553	17 465
NH3	mg	0	- 18	0	0	- 18
Dust	mg	2 091	2 015	1 718	373	296
HCl	mg	16.46	15.66	5.47	11.00	10.19
HF	mg	0.54	0.54	2.58	-2.03	-2.03
HBr	mg	0.00	0.00	0.00	0.00	0.00
Metals (total)	mg	9.63	9.17	2.54	7.08	6.63
Sb	mg	0.27	0.27	0.26	0.02	0.02
As	mg	0.33	0.33	0.07	0.26	0.26
Pb	mg	0.59	0.59	0.17	0.42	0.42
Cr	mg	0.12	0.12	0.03	0.09	0.09
Co	mg	0.51	0.51	0.10	0.41	0.41
Cu	mg	3.09	3.09	0.62	2.46	2.46
Mn	mg	1.44	1.44	0.30	1.14	1.14
Ni	mg	0.49	0.49	0.12	0.38	0.38
V	mg	0.97	0.52	0.25	0.72	0.27
Sn	mg	0.56	0.56	0.12	0.44	0.44
Hg	mg	0.31	0.31	0.09	0.22	0.22
Cd	mg	0.21	0.21	0.20	0.00	0.00
Dioxins	µg	0.00494	0.00306	0.00429	0.00065	-0.00123
EMISSIONS TO WATER						
Volume	litres	25.51	25.51	0.43	25.08	25.07
COD	mg	8.09	8.08	2.77	5.32	5.31
BOD	mg	3.98	3.98	1.34	2.64	2.64
Acid	mg	23.13	23.13	7.51	15.62	15.62
Nitrates	mg	1.04	1.04	0.44	0.60	0.60
Sulphates	mg	0.25	0.24	0.17	0.08	0.07
Metals	mg	3.88	3.88	1.26	2.62	2.62
Ammonium	mg	1.29	1.29	0.62	0.67	0.67
Cl	mg	7.72	7.72	2.51	5.21	5.21
Suspended solids	mg	102.29	102.28	30.95	71.34	71.33
Hydrocarbons	mg	16.15	16.12	6.96	9.19	9.16
Other N	mg	0.77	0.77	0.25	0.52	0.52
Total DS	mg	303.90	302.21	201.00	102.90	101.20
Br	mg	0.0001	0.0001	0.0000	0.0001	0.0001
F	mg	0.0001	0.0001	0.0000	0.0001	0.0001
Sb	mg	0.000001	0.000001	0.000000	0.000001	0.000001
As	mg	0.000001	0.000001	0.000000	0.000001	0.000001
Pb	mg	0.000000	0.000000	0.000000	0.000000	0.000000
Cr	mg	0.000000	0.000000	0.000000	0.000000	0.000000
Co	mg	0.000002	0.000002	0.000000	0.000002	0.000002
Cu	mg	0.000012	0.000012	0.000000	0.000012	0.000012
Mn	mg	0.000005	0.000005	0.000000	0.000005	0.000005
Ni	mg	0.000001	0.000001	0.000000	0.000001	0.000001
V	mg	0.000001	-0.000001	0.000000	0.000001	-0.000001
Sn	mg	0.000002	0.000002	0.000000	0.000002	0.000002
Hg	mg	0.000000	0.000000	0.000000	0.000000	0.000000
Cd	mg	0.000001	0.000001	0.000000	0.000001	0.000001
SOLID WASTES						
Inert inorganic	mg	692 178	692 176	195 899	496 279	496 277
Other industrial	mg	740 971	739 908	724 449	16 522	15 459

3.3.2 Other options

Two further sensitivity cases are relevant:

- deeper solvent recovery
- use of other clean fuel in the cement kiln.

For both of these, the oxygenated waste is used as illustration.

Deeper solvent recovery

With the deeper solvent recovery, a recovery of 80 percent of total waste feed is assumed. Instead of passing to an incinerator, the residues are sent to landfill.

The results of this sensitivity case are summarised on Figure 3.13. The deeper recycle case shows lower impacts than the case with 65 percent recovery. In particular, the loss of metal compounds to atmosphere is reduced by avoiding the need to incinerate residues.

This analysis relates to the reprocessing of the total waste, not to the incremental benefits of moving from 65 percent to 80 percent recovery.

Clean fuel

If a cleaner fuel than coal or petcoke were used in the cement kilns, the burdens avoided by use of SLF would be lower. Natural gas can be used and is on some plants in the United States. The economics of production and fuel costs in Europe make gas burning an unattractive option for cement producers. The case is included to illustrate the technical comparisons rather than as a practical solution.

The inventory is presented in Table 3.14 and summarised on Figure 3.14. It is apparent that the impacts are significantly reduced when natural gas is used in the kiln. For several parameters, the benefits of switching to natural gas are comparable to, or lower than, those of redirecting organic wastes from incineration to SLF.

Table 3.14 Life Cycle Inventory data: clean fuel to cement kiln option

All data expressed per kg waste		SYSTEM I INCINERATION	SYSTEM II CEMENT KILN	SYSTEM I INCINERATION	SYSTEM II CEMENT KILN
	Units	Cement Kiln with coal, petrocoke	Cement Kiln with SLF, coal, petrocoke	Cement Kiln with natural gas	Cement Kiln with SLF, gas
MATERIALS					
Coal	kg	1.44	0.77	0.21	0.21
Oil	kg	0.83	0.43	0.11	0.10
Gas	kg	0.04	0.03	1.16	0.62
Iron ore	kg	0.08	0.08	0.08	0.08
Limestone	kg	7.10	7.09	7.10	7.09
Bauxite	kg	0.00	0.00	0.00	0.00
NaCl	kg	0.00	0.00	0.00	0.00
Sulphur	kg	0.00	0.00	0.00	0.00
Clay	kg	3.04	3.04	3.04	3.04
Sand	kg	0.03	0.00	0.03	0.00
Water consumed	kg	34.08	8.13	33.48	7.84
ENERGY					
Feedstock	MJ	0.01	0.00	0.01	0.00
Processing: renewable	MJ	1.30	1.01	1.16	0.94
Processing: non-renewable	MJ	75.51	40.35	62.89	34.24
Transport	MJ	1.88	1.98	1.87	1.98
Total energy	MJ	78.70	43.34	65.92	37.15
EMISSIONS TO AIR					
CO2	mg	11 279 725	8 299 579	8 936 633	7 164 594
CO	mg	17 633	15 942	13 326	13 855
CH4	mg	27	21	24	20
General HC	mg	2 836	1 836	2 134	1 493
NOx	mg	68 000	51 385	46 679	41 054
SO2	mg	30 775	16 637	4 251	3 795
NH3	mg	-0.20	-0.09	-0.13	-0.06
Dust	mg	2 062	1 762	1 842	1 654
HCl	mg	15	12	2	5
HF	mg	0.54	2.58	0.51	2.57
HBr	mg	0.00	0.00	0.00	0.00
Metals (total)	mg	17.58	17.43	14.93	16.15
Sb	mg	0.27	0.26	0.25	0.25
As	mg	0.33	0.09	0.25	0.05
Pb	mg	2.09	1.78	1.50	1.50
Cr	mg	1.57	0.33	1.50	0.30
Co	mg	0.51	0.10	0.50	0.10
Cu	mg	3.09	0.64	3.00	0.60
Mn	mg	1.44	0.34	1.25	0.25
Ni	mg	0.49	0.17	0.25	0.05
V	mg	0.97	0.40	0.25	0.05
Sn	mg	0.56	0.13	0.50	0.10
Hg	mg	5.31	12.63	5.00	12.48
Cd	mg	0.21	0.20	0.20	0.20
Dioxins	µg	0.00477	0.00421	0.00444	0.00405
EMISSIONS TO WATER					
Volume	litres	25.50	0.73	24.85	0.42
COD	mg	8.08	4.26	5.45	2.99
BOD	mg	3.98	2.08	2.67	1.45
Acid	mg	23.13	11.93	15.36	8.16
Nitrates	mg	1.03	0.60	0.75	0.46
Sulphates	mg	0.24	0.18	0.21	0.17
Metals	mg	3.88	2.00	2.58	1.37
Ammonium	mg	1.29	0.80	0.97	0.64
Cl	mg	7.72	3.99	5.13	2.73
Suspended solids	mg	102.27	51.05	60.77	30.95
Hydrocarbons	mg	16.09	9.45	11.64	7.29
Other N	mg	0.77	0.40	0.51	0.27
Total DS	mg	300.16	221.38	258.32	201.12
Br	mg	0.0001	0.0000	0.0001	0.0000
F	mg	0.0001	0.0000	0.0001	0.0000
Sb	mg	0.000001	0.000000	0.000001	0.000000
As	mg	0.000001	0.000000	0.000001	0.000000
Pb	mg	0.000006	0.000000	0.000006	0.000000
Cr	mg	0.000006	0.000000	0.000006	0.000000
Co	mg	0.000002	0.000000	0.000002	0.000000
Cu	mg	0.000012	0.000000	0.000012	0.000000
Mn	mg	0.000005	0.000000	0.000005	0.000000
Ni	mg	0.000001	0.000000	0.000001	0.000000
V	mg	0.000001	0.000000	0.000001	0.000000
Sn	mg	0.000002	0.000000	0.000002	0.000000
Hg	mg	0.000001	0.000000	0.000001	0.000000
Cd	mg	0.000001	0.000000	0.000001	0.000000
SOLID WASTES					
Inert inorganic	mg	692 174	335 217	375 351	181 833
Other industrial	mg	739 602	726 574	734 931	724 313

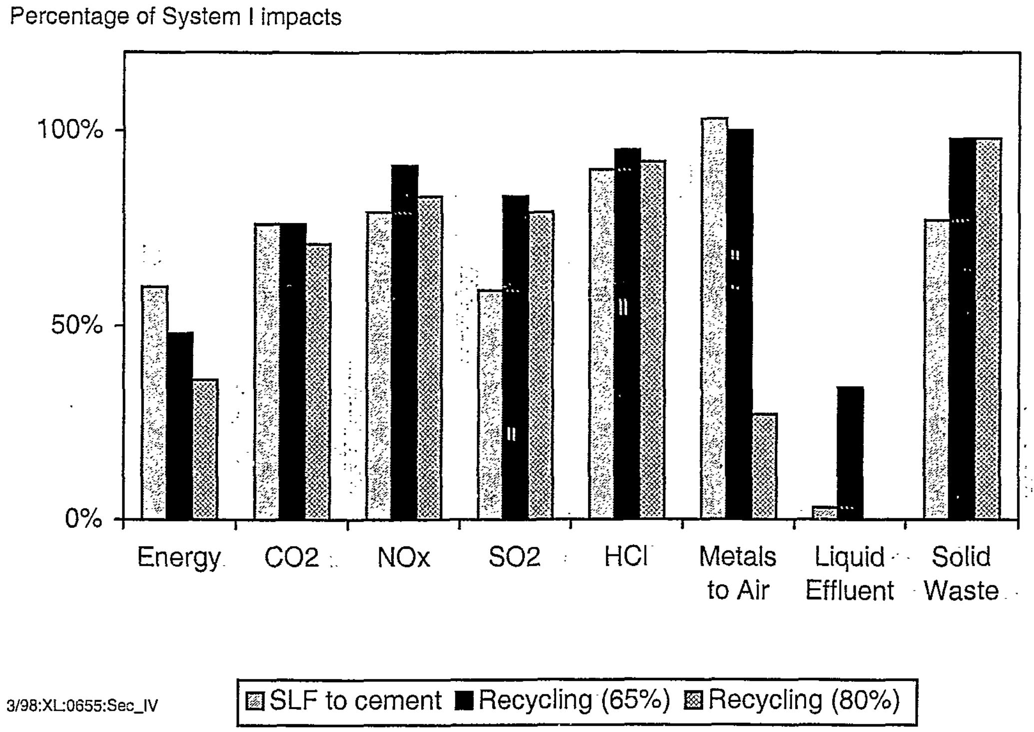


Figure 3.13 Impacts as percentage of incineration impacts: deep recovery case

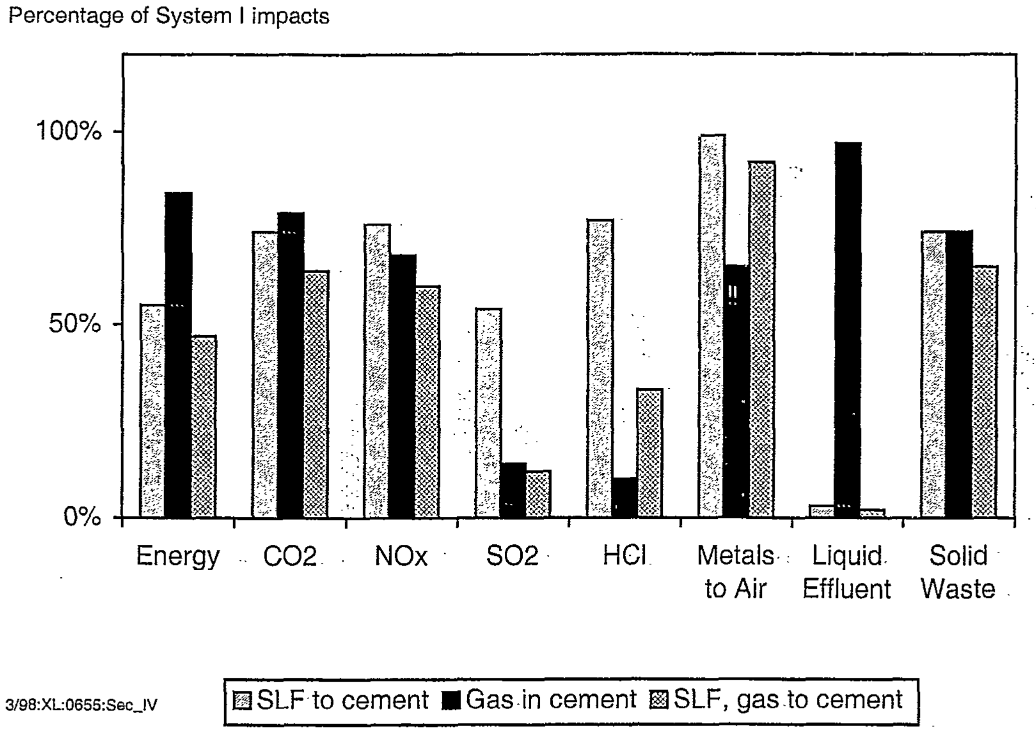


Figure 3.14 Impacts as percentage of incineration impacts: clean fuel to cement kiln

3.4 Environmental Impact Analysis

3.4.1 Background

If all the environmental burdens were to increase, or all decrease, in changing from one disposal route to another, then the conclusion of the LCA would be clear. There would be no need to perform any form of impact analysis. This is the ideal case, because impact assessment techniques within LCA can introduce elements of value judgement or uncertain correlations. Where there are trade-offs, such as between emissions of CO_2 and solid waste, then further analysis is required on these trade-offs.

The results of the Life Cycle Inventory (LCI) are presented in Section 3.3. Certain conclusions may be drawn from the LCI results. The interest is always in the differences between options, not the absolute values of burdens in any system. This is particularly important when the LCI is calculated on the basis of an increment of material in a larger system.

The burdens in converting waste to SLF and using in cement kilns are generally significantly lower than those in which the waste is sent to incineration. In either case, the waste is burnt, but in the SLF route part of the usual cement kiln fuels are not burnt. The advantage lies in avoiding the impacts of producing, grinding, and burning these usual fuels.

There are, however, exceptions to the advantages of SLF. For some pollutants, the percent retention is higher for an incinerator than for a cement kiln. This might outweigh the benefits of avoiding burning coal and petcoke. From the limited data, it appears that this applies to emissions of hydrogen chloride (HCl) and other hydrogen halides, but this might be dependent on the total quantity waste. It may also apply to some more volatile metals, though the data are even less clear.

Some consideration of how to value emissions of different pollutants is therefore needed.

When the SLF route is compared to recycling, the picture is rather more mixed, and depends upon the solvent in question. If the solvent has a high energy content and there are relatively low burdens in its manufacture, the SLF route appears consistently preferable. This is because the SLF is replacing large quantities of coal and petcoke. Toluene is the hypothetical example that fits this category. For other solvents, such as acetone, the recycling route may be of benefit in saving energy (natural resources), but not as beneficial as SLF in most other respects.

A simplified form of Impact Analysis is therefore needed to review these few instances of trade-off between burdens.

3.4.2 SLF to Cement Kilns and Incineration

In Life Cycle Assessment, a common technique is to define a number of environmental impact categories and calculate the contributions to each category in a common currency. Contributions, to global warming would be calculated as kilograms of carbon dioxide, for example. The impact categories typically include at least those shown on Table 3.15.

Table 3.15 Example of LCA Impact Categories

Category	Unit	Conversion on
Energy	MJ	Primary energy
Global Warming	kg CO_2	Global Warming Potential
Ozone Depletion	kg CFC 11	Ozone Depletion Potential
Ozone Creation (VOCs)	kg ethylene	Photochemical Ozone Creation Potential
Acidification	kg SO_2 or H+	Stoichiometry
Human toxicity (air)	Volume	Reciprocal of allowable concentration
Toxicity (water)	Volume	Reciprocal of allowable concentration
Eutrophication	kg P	Stoichiometry
Solid waste	kg	Mass

The conversion methods range from the scientifically agreed to rather pragmatic and potentially inaccurate measures.

The trade-offs between incineration and SLF recycling are fairly simple, as noted above. Therefore an analysis is made firstly on human toxicity (emissions to air category) to check whether HCl emissions are trivial compared to others, such as SO_2 and NOx. The simple weighting method of dividing mass emissions by an acceptable concentration is used. This is comparable to the Environmental Quotient system for BPEO Assessments (Technical Guidance Note E1). In this system, the ambient concentration caused by the process is divided by the Environmental Assessment Level (EAL). The simple weighting system used in the LCA makes use of the long term EALs, but omits the plant-specific relationship between mass emission and ground level concentration.

Table 3.16 shows the results of the calculations. For each pollutant, the mass in the table is the largest difference between systems out of all the cases considered. The maximum difference for HCl occurs in the hypothetical trichloroethylene waste case. On the basis of this calculation, the HCl emissions do not appear trivial compared to others. The metal compounds emitted to air appear a less important factor, but not insignificant. This reflects the comparatively small amounts of metals in the various wastes and fuels, compared to the very high percentage of chlorine in trichloroethylene.

Table 3.16 Differences in atmospheric emissions weighted by EAL

Pollutant	Mass per Functional Unit *(mg)*	Long Term EAL[1] *($\mu g/m^3$)*	Mass/EAL *(volume : 000m^3)*
NOx	42 900	40	1 073
SO_2	17 600	100	176
HCl	2 590	7	370
Particulates	420	50[2]	8
Mercury	7	1	7
Cobalt	1	0.2	5
All metals	16	Various[3]	25
CO	2 000	550	4

(1) EALs from Technical Guidelines Note (Environmental) E1.
(2) Short term EAL; lower than EC annual limits.
(3) Volume aggregated for all metals.

The EAL for HCl is much lower than for SO_2 and NOx. Even if it were not, the HCl would still be reasonably significant in the case of a unit of heavily chlorinated waste. The HCl would also be quite important in terms of acidification, compared to SO_2. Therefore the higher HCl emissions when the waste is heavily chlorinated cannot be treated as trivial.

The systems analysed contribute to other impacts as well as toxic effects of atmospheric emissions and acidification. If the contribution of the systems to, for example, global warming are very much more important than contributions to toxic atmosphere pollution, then the findings presented above might be more than outweighed in some cases. One way of assessing the relative contributions is to present the burdens from the system studied as a percentage of the total annual national burden. This is not possible for many variables for which national inventories are not recorded. Table 3.17 shows the energy consumptions, and emissions of carbon dioxide, sulphur dioxide, and nitrogen oxides. In each case, the maximum difference between systems is divided by UK national data (1995). The relative contribution to national burdens is roughly comparable for these variables. In other LCAs, the ratio might vary by several orders of magnitude, suggesting some impacts may be insignificant: not the case here.

Table 3.17 Differences in environmental burdens per functional unit divided by total UK burdens per year

	Ratio x 10^{-12}
Primary Energy	6.4
CO_2	7.9
SO_2	4.6
NOx	15.5

A final step in the analysis could be to attach different ratings of importance to each environmental issue. Is global warming a more serious problem than human health, for example? This type of approach is different to justify scientifically, but several methodologies are available including economic valuation of impacts. Because of the limited nature of the trade-offs in this LCA, and the uncertainties in valuation methods, this is not pursued further.

If constituents, such as halogens or more volatile metals, are present at significant concentrations in the organic waste, then the SLF route may show disadvantages in the relevant emissions. The simplified analysis of environmental impact suggests that these "trade-off" factors are not insignificant for halogens. They should be included in any consideration of wastes to be excluded from the SLF route.

3.4.3 Recycling and SLF

An impact analysis for recycling and SLF would be very complex as the data are different for each solvent. It is clear from Table 3.17 above that the saving of primary energy resources is not trivial compared to other impacts, so that any trade-off between resource consumption and pollution cannot be ignored.

It would be very difficult to produce a definition of wastes that should be recycled rather than sent to SLF, based on environmental impact analysis. For practical purposes, the following qualitative points are made:

- recycling is environmentally preferable to incineration on almost every count
- recovery of a high percentage of solvent, leaving a dry residue that can be landfilled, is preferable to recovery at 60 to 70 percent and incineration of residues
- economics (see Section 5) will encourage recycling of mixed solvents where possible, although will not necessarily encourage deep recovery with dry residues
- the economics of single solvent recovery are substantially better than those of SLF blending.

3.4.4 Liquid and solid wastes

The simplified review presented above focuses on atmospheric emissions and, to a lesser extent, consumption of hydrocarbon resources. A brief commentary is needed on aqueous effluent and solid wastes.

Aqueous effluents

Aqueous effluents arise mainly, in the cases considered, as incinerator scrubber effluents. As the incinerator option is less environmentally beneficial than SLF in several other respects, the importance of aqueous effluents does not need to be examined in detail.

In addition, the masses of pollutants in the effluent, such as metals, are generally rather lower than those emitted to atmosphere. The effluent stream is saline, and this could constitute an environmental burden for some receiving water bodies. However, annual quantities are very low compared to certain major inorganic chemical production processes, and there is no indication that salinity of incinerator effluent is a cause of concern.

Solid wastes

A large part of the contaminants in organic waste become part of the solid streams, both clinker product and residues.

In the LCA, it is assumed that solid wastes of this sort would be sent to special waste landfills, with careful control and treatment of leachate. Tests on cement kiln dust (CKD) (Reference: Burning Hazardous Waste in Cement Kilns, ETI, 1992) indicate that leachability is acceptably low whether conventional fuel or SLF is used. If the CKD is recycled, the contaminants largely remain in the clinker product. This needs to meet product specifications appropriate to its use in construction.

Neither aqueous effluents nor solid wastes are identified as a major environmental factor in the LCA.

3.5 Conclusions of Life Cycle Assessment (LCA)

3.5.1 Basis of analysis

The LCA is calculated to show the differences in environmental impact if one kilogram of waste is sent to different disposal routes. For the liquid organic wastes of relevance to SLF, landfill or disposal to surface water are taken not to be options within the current and expected regulatory framework. The disposal routes considered are therefore incineration, blending to SLF for use in cement kilns, and recycling.

3.5.2 Incineration and SLF to cement kilns

Blending organic wastes into SLF and burning in cement kilns is preferable to disposal by incineration for most of the parameters considered in the LCA. This is because the SLF is replacing conventional cement kiln fuels, coal and petcoke. Very similar advantages, or greater for some variables, could be gained by burning natural gas in cement kilns. This is cited to illustrate the technical analysis, not as an economically viable option.

For organic wastes of similar composition to typical blended SLF, there are some exceptions to the advantages of the SLF route. The key determinant is the retention of contaminants in the waste by the cement kiln and by the incinerator. Incinerators have very efficient gas cleaning trains. The analysis suggests that emissions of halogen compounds to atmosphere, expressed as HX, will be higher for the SLF route than for incineration if the SLF contains a moderate halogen content. A similar argument probably applies to semi-volatile and volatile metals, though the data on retention efficiencies are not clear.

3.5.3 Varying waste compositions

(a) Concentrations of contaminants in waste

The study is intended to review whether some wastes should be excluded from SLF. Different waste compositions were used in the LCA; the net impact of an incremental quantity of the waste is examined. However, as noted in Section 3.1.2, the impact could depend upon the quantity of the waste. Some contaminants may be absorbed in clinker up to a certain quantity, above which breakthrough occurs. Metal compounds and halogen compounds are examples of this phenomenon. This means that caution is needed in drawing inferences on the impact of small quantities of component wastes in total SLF. It also suggests that the principle of excluding certain wastes from a blend may be difficult to justify rigorously. These reservations are very relevant to the following discussion of results.

The LCA results indicate that the concentration of contaminants in the organic waste need to be lower than those in the alternative cement kiln fuels if the SLF route is to show an advantage. This should be expressed on the basis of energy units – such as grams per MJ – rather than weight percent.

The sulphur limit of blended SLF is usually very much lower than the alternative cement kiln fuels, leading to reduced SO_2 emissions. If sulphur is increased to around 0.75 g per MJ, the SLF route will not be advantageous in terms of SO_2 emissions because there would be no advantage over the usual cement kiln fuels. In practice, of course, the quality of the usual fuels varies, so that the break-point quality of SLF theoretically also varies between plants and the fuel of the time.

A similar argument applies to halogens. Highly chlorinated wastes in sufficient quantities will give rise to more HCl from cement kilns than from incinerators. There is an understandable concern that dioxin emissions might also rise with increased chlorine content. Incinerators are designed to minimise dioxin formation while cement kilns are production plants with a different design emphasis. In practice, both cement kilns and incinerators can be operated with dioxins reliably controlled to under 0.1 ng/m^3.

For oxides of nitrogen, the quantity of thermal NOx created depends on factors such as flue gas volume, temperature, and oxygen content. If the SLF is sent to the cement kiln, it displaces conventional fuels and the processing operations necessary to produce them. When SLF is added to an incinerator running on a previously balanced burn menu, there is an additional NOx load. The net effect is a reduction in NOx emissions when the waste is routed to cement kilns. The nitrogen content of the waste influences the quantity of fuel NOx. There is, however, no clear reason to distinguish between cement kilns and incinerators in the case of fuel NOx.

Both cement kilns and incinerators exhibit very high retention of metals. On the data available, it is likely that high concentrations of semi-volatile and volatile metals would lead to increased emissions in the SLF route. The bulk of the metals remain in solid residues and, in the case of cement, in the clinker product. Leachability is not identified as a problem. Incinerator residues and the cement kiln dust (where produced) will in any case be landfilled with appropriate controls.

(b) Aqueous wastes

If pure water were sent to an incinerator or a cement kiln, additional fuel could be needed in both cases. The incinerator would be the preferred route because of cleaner fuel and better retention than cement kilns. This is assuming the use of low sulphur gas oil in the incinerator, as quoted to Chem Systems by an operator, and coal plus petcoke in cement kilns.

However, in a case considered with 90 percent water, the SLF route shows a mixture of environmental advantage and disadvantage, depending on the parameter examined.

(c) Total and incremental load

The LCA is calculated on the basis of one kilogram of organic waste to permit the effects of different waste types to be analysed.

In practice, there are factors that relate to the total cement kiln loading. The total quantity of acid gases might exceed the capacity of alkaline materials to retain them, for example. There are also interactions, such as if high chlorine loadings tend to lead to higher emissions of lead and some other metals in the form of volatile chlorides, as reported in the literature.

These factors cannot be considered meaningfully when considering individual wastes that are blended into SLF.

3.5.4 Recycling

The analysis of solvent recovery and recycling is complex as the avoided burdens of new solvent vary with the type of solvent.

- Recycling is environmentally preferable to incineration on almost every count.
- Recovery of a high percentage of solvent, leaving a dry residue, is environmentally preferable to recovery at 60-70 percent with incineration of residues.
- Recycling is not necessarily preferable to the SLF route. This depends on the solvent type. The comparison between recycling and SLF shows trade-offs in some areas.

It is not easy to define wastes that should be recycled rather than sent to SLF for environmental reasons. However, it should be noted that there is an economic incentive to recycle solvents (see Section 4), particularly single solvents rather than solvent mixtures. Because an economic incentive is in place, it is not proposed to attempt to define "recoverable" wastes that should not be blended into SLF.

3.5.5 Excluded wastes

The Environment Agency has set standards for blended SLF at certain cement works. The standard is different for each plant, reflecting the characteristics of each. As the Life Cycle Assessment indicates, the use of this SLF is of environmental benefit for most variables, in comparison with other disposal routes.

Some SLF blenders have their own guidelines for the exclusion of wastes. These include materials that are perceived to be of particular sensitivity to the public, such as PCBs. Materials that are highly toxic, or clinical wastes, may also be excluded to reduce risks to employees and the public arising from handling and transfer. Such restrictions are commendable, but are not part of the Life Cycle Assessment study. The risks of handling and transfer would occur whichever disposal route were selected, if comparable equipment is used in each.

Proposals for excluded wastes must be expressed in terms of compositions. Exclusion of wastes from certain sources of certain types would be insufficiently precise because of the range of compositions in each category.

It must also be recognised that any exclusion limit will exclude the whole waste, not only the particular component. A waste that is pure hydrocarbon plus four percent sulphur might be excluded on the grounds of sulphur content. Other than the increase in SO_2 emissions, there would be significant advantages in the SLF disposal route for such a waste. Individual component limits therefore need to be set high, at a level where the component pollution would be serious compared to other environmental advantages.

Restrictions already imposed by the Environment Agency on blended SLF are the main tool for controlling environmental burdens. They can take account of the specific details of the kiln and factors relating to the total mass flows rather than a small increment of waste. The principle of excluding individual wastes is difficult to justify rigorously because the net impact may depend on the total quantity.

If it is required to also exclude specific individual wastes, then the criteria could be:

- wastes of significantly worse quality than usual cement kiln fuels, so there is a disadvantage in blending in SLF
- wastes of very low calorific values, for the same reasons
- wastes with a high halogen content, because incineration offers better retention (on available data) – if used in large quantities
- wastes with high concentrations of volatile or semi-volatile metals, for the same reason – if used in large quantities

- wastes for which combustion processes may not be ideal, such as those with very high metals contents or ash contents.

Suggestions are presented in Table 3.18 of possible restrictions on the composition of individual wastes being blended with SLF. There is no rigorous methodology underlying the suggestions of composition limits. Instead, the limits reflect the results of the LCA, with the intention of excluding heavily chlorinated wastes, for example. Attention has also been paid to be data available on individual waste compositions to ensure that levels are realistic. Reference has also been made to the existing specifications for blended SLF.

Table 3.18 Possible exclusion limits for individual wastes being blended to SLF

	Unit	Limit (maximum unless noted)
Calorific value (LHV)	MJ/kg	3.0 (minimum)
Sulphur	g/MJ	1.5
Nitrogen	g/MJ	1.5
Any halogen	g/MJ	4.0
Total halogens	g/MJ	6.0
Ash	g/MJ	25.0
Mercury	mg/MJ	2.0
Thallium	mg/MJ	2.0
Total mercury plus thallium	mg/MJ	3.0
Cadmium	mg/MJ	10.0
Total semi-volatile metals(1)	mg/MJ	75.0
Total metals	mg/MJ	350.0

Note: (1) See definitions in Section 3.2.2(b)

All the restrictions imposed by the Environment Agency on the blended SLF should still apply. These are rather more stringent than those in place in several other countries where SLF is used in cement kilns.

The consequences of the limits suggested on Table 3.18 would be:

- exclusion of substantially aqueous wastes, which arise in just about every industry sector as washings etc

- exclusion of heavily halogenated streams, which would be certain streams such as, for example:

  - waste solvents from fine chemical production
  - waste tars from fine chemicals production
  - solvents from surface cleaning
  - solvents from adhesive applications

- exclusion of wastes with higher metal contents than typically found in wastes currently blended into SLF; likely sources are:

  - coatings waste with high metallic pigment content, such as from the automotive industry

  - residues from solvent recycling.

There are practical points relating to any control of individual component wastes entering SLF.

- Wastes delivered to SLF blenders may be supplied by waste contractors from a collection round. The waste may be a bulked-up mixture of material from several sources. Restrictions to prevent "inappropriate" wastes from entering these streams would be difficult in administrative terms. Conversely, any limits on individual waste components could be circumvented if wastes are supplied to the blender as a bulked-up mixture.

- The correct approach for any cement kiln could depend upon the exact chemistry and other factors relating to that kiln. For example, some kilns actually require an addition of chloride content when insufficient is present in the feedstock. This is of relevance mainly to the total blended SLF. Some consideration is needed, however, of how to give Inspectors room for discretion if a kiln has a demonstrably high retention of specific pollutants or other special features.

- Exclusion of specific wastes would require more analysis than is currently performed by blenders when producing SLF. Metal content is typically not analysed for each consignment, for example. There would be substantial practical and economic difficulties in any exclusion system, although regulation on a spot check basis is an option to consider.

4. Economic and Market Issues

4.1 Economics

4.1.1 Introduction

The main question is whether the market for SLF in cement kilns provides an economic incentive to use disposal routes with higher environmental impacts than others. Specific points are:

- whether recyclable wastes might be sent as SLF to cement kilns or incinerators instead of being recycled

- whether high CV incinerable wastes are attracted into SLF rather than being sent to merchant incinerators, making it more difficult for incinerator operators to burn a mixture of wastes economically.

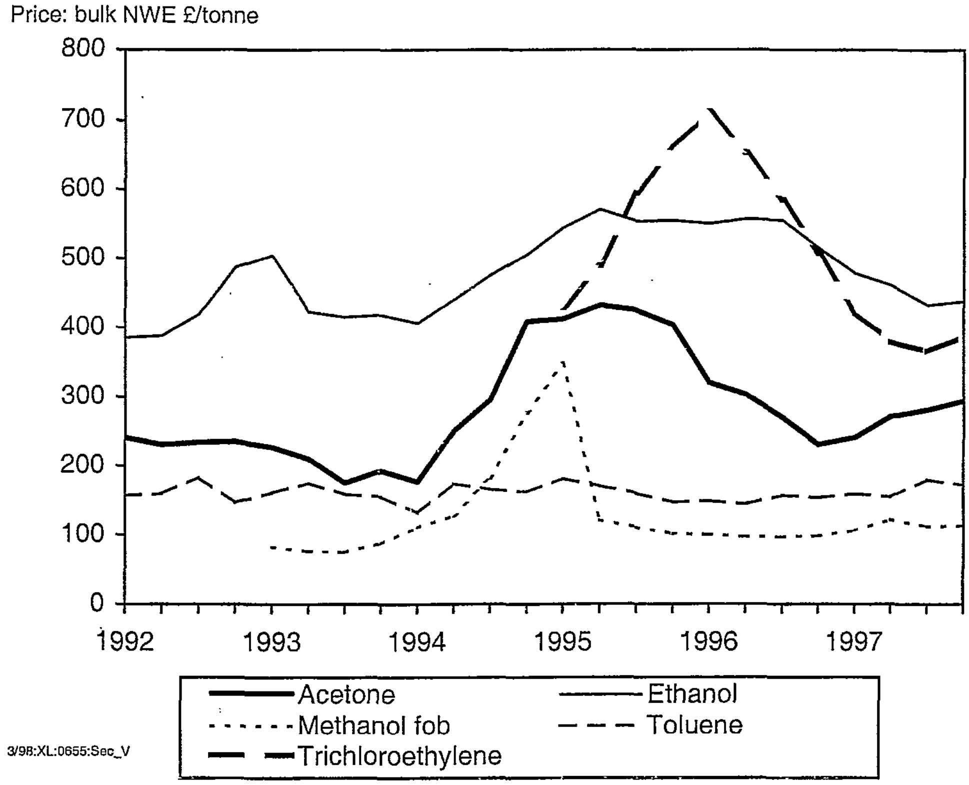
There are various cost and price elements of relevance, and these are reviewed below. All cost estimates are only approximate. Although Chem Systems received data in confidence from a number of operators, the information presented here is typical rather than specific to any site. The figures have been altered slightly to aid confidentiality, but not to an extent that affects directional conclusions. It should also be recognised that costs will vary with waste type.

4.1.2 Solvent prices

Solvents may be recovered from organic wastes either as single solvents, such as acetone, or as a mixture, often termed thinners.

The price achieved for recycled single solvent is related to that for new solvent. Depending on the quality of the recycled material and the needs of the application, recycled solvent typically commands a price of 50 to 70 percent of that of new solvent.

Bulk production of new solvents is essentially a commodity business in which prices are related to production costs and the balance of capacity and consumption. Prices of new solvents tend to fluctuate with the industry business cycle, as Figure 4.1 illustrates. As recycling economics are not as strongly linked to the chemical industry cycle, this means that the margin available to recyclers should also fluctuate.



Note: NWE = North-West Europe

Figure 4.1 Prices of selected solvents

The prices shown on Figure 4.1 are for large contracts. Smaller quantities, sold through distributors, will carry further costs and margins. This could be, very roughly, £50-£100 per tonne for road tanker loads. For drummed solvent, the delivered price might be of the order of twice that of the bulk price.

The price for thinners is not linked closely to that of new solvent. It is highly dependent on supply and demand. A typical price range is £80 to £120 per tonne. However, it has been known for recyclers to receive zero netback in times of glut.

4.1.3 Final disposal costs

The gate fee charged by merchant incinerators depends on several factors, including the form of delivery, the calorific value, and the chemical composition. For this analysis, the usual fee to the waste producer is taken to vary between £50 to £300 per tonne for wastes of relevance to the study of SLF. This figure is a price, not cost, and includes the margin taken by the incinerator operator. The same figures are used for on-site incinerators on the premise that the unit could otherwise be used on a merchant basis.

In compliance with regulatory trends, landfill should not be considered as a long term option for liquid solvent wastes and similar. With deep recovery of solvent (see below), a solid residue is left that can be landfilled. The landfill may be on-site or external. A cost range of £5 to £30 per tonne is assumed, to the waste producer.

4.1.4 SLF prices and costs

For a cement kiln operator, the SLF displaces other fuels. There are additional set up costs in burning SLF, such as the need for tankage and pumps, and running costs that include analytical work. Cement kiln operators are also aware that the provider of SLF would face the cost of alternative means of disposal if the material were sent elsewhere. It is Chem Systems' understanding that the cement kiln may pay a price for the SLF or may charge a gate fee. This is typically the subject of a confidential formula that includes the energy content, and makes allowance for unwelcome components. The kiln chemistry dictates which components are unwelcome; in some cases they might include chlorine, for example.

A range of £20 fee to £20 credit is taken as typical for SLF.

The production costs of SLF are not insignificant. Material supplied in drums must be removed in a drum handling facility. Extensive analysis is needed of the wastes and the material must be blended to meet the SLF specification established by the Environment Agency. For drum handling, costs of £15 to £25 per tonne are assumed. The cost of SLF blending is taken as £25 to £45 per tonne. These figures include site overhead as well as direct costs, but not depreciation and margin.

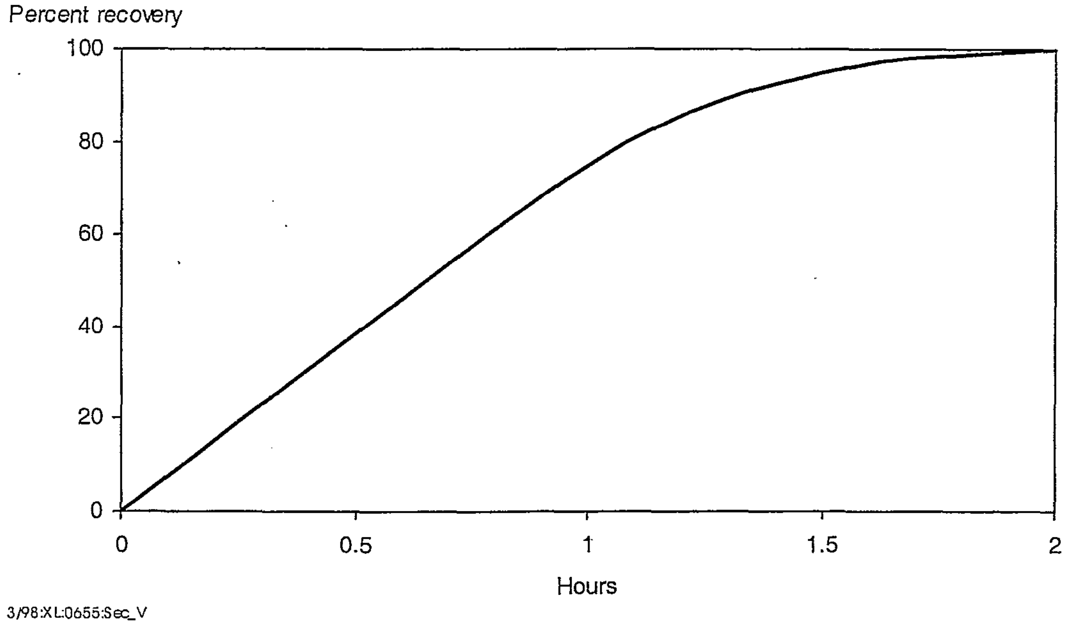
4.1.5 Recycling costs

Two cases of recycling are reviewed. The first is the case in which recovery is around 65 percent, and the residue can be handled as a liquid. There is then a choice of disposing of the residues by sending to incineration, or by blending into SLF.

In the second case, the solvent recovery proceeds until a dry residue is produced. Solvent recovery might be around 80 percent and the residue can be sent to landfill.

Recycling is performed on batch stills. Figure 4.2 indicates the diminishing recovery with time as the distillation progresses. The cost of processing a tonne of waste increases significantly as the percentage recovery increases. The solvent recovered at higher percentage recovered tends to be coloured, and needs further processing to achieve commercial clarity.

The cost of processing one tonne of waste is taken as £40 to £60 per tonne for recovery at 65 percent, and £60 to £90 per tonne at 80 percent. As with SLF processing, this does not include depreciation and margin. The costs of drum handling need to be added for drummed waste.



Source: Croda Hydrocarbons

Figure 4.2 Solvent recovery versus processing time

4.1.6 Other

Other costs include transport, with documentation. The transport element is highly dependent on location, so is not included in the estimates. The absolute values of costs will therefore vary with location.

A nominal margin of £30 per tonne to the SLF blender or the solvent recycler is included in the estimates.

4.1.7 Comparison of costs

A comparison of costs for the disposal of mixed solvents wastes is given in Table 4.1. The solvent recovered is the thinners grade. Solvent recovery is shown at 65 percent, with residue going to SLF or incinerator, and at 80 percent with residue going to landfill. The other options are total incineration in a merchant facility, or total blending into SLF. The costs in the table are "typical". The gate fee that the recycler or blender needs to charge is quoted for the typical case and for the best and worst extremes. The best extreme combines highest prices and lowest costs, for example (not shown on table). All these costs are intended to allow comparison of differentials.

Table 4.1 Indicative economics of disposal routes (£ per tonne waste feed)

Residue>>>	Incineration	All to SLF	Recycle(3) Incineration	Recycle(3) SLF	Deep Recycle(4) Landfill
Revenue		0	65	65	80
Drum handling(1)		10	10	10	10
Processing		35	50	50	75
Residue processing				12	
Residue disposal	125		44	0	4
Margin		30	30	30	30
Gate fee(2): typical	**125**	**75**	**69**	**37**	**39**
Gate fee: best	50	43	17	1	3
Gate fee: worst	300	115	158	64	101

(1) 50 percent drummed

(2) Gate fee at recycler/blender/waste company.

(3) Thinners grade; 65 percent recovery.

(4) Thinners grade; 80 percent recovery.

The SLF route appears to be considerably cheaper than sending all the waste to high temperature incineration. This tends to support the argument by incinerator operators that SLF is capable of poaching certain wastes from incineration. As the pricing formulae for incinerator feed and SLF are likely to be directionally similar, this conclusion should hold over a reasonable range of compositions.

The incinerator operators argue that SLF takes high calorific value (CV) material and so makes it economically difficult to burn low CV wastes, such as those containing a high proportion of water. If incinerators were used to take SLF-type wastes at rates that compete with SLF blenders, the price for low CV wastes would need to be correspondingly increased. Whether this is acceptable to the producers of low CV waste depends on alternative disposal routes and regulatory restrictions on methods of disposal. As noted in the LCA analysis, this is a broad question of regulation, enforcement and motivation.

The data on Table 4.1 also show the advantage to the solvent recycler (65 percent recovery) of sending residues to SLF rather than to incineration. Without this option, the gate fee for recyclable wastes would be significantly higher. If the recycling residues are blended into SLF, then recycling is more economically attractive than sending the total waste to SLF. This important conclusion would hold even if the recovery rate were only around 50 percent. This supports the contention by SLF blenders that there is no economic incentive to take whole waste streams from recycling.

The remaining question is whether it is economically worthwhile to recover a further quantity of solvent from the residues, rather than sending it to SLF. From the data on the deep recycle (80 percent recovery) case, the answer is not clear. With the uncertainties in the approximate data, it is likely that either route could be more economically attractive in different specific cases.

All the above comments relate to the production of thinners. Single solvent streams usually command a higher price, in some cases considerably so. Methanol is an exception (see Figure 4.1) because it is produced in one plant step from cheap feedstock, natural gas. Recycling routes are therefore likely to be strongly favoured compared to SLF blending if single solvents can be recovered.

This is illustrated on Figure 4.3, in which the gate fee charged by the recyclers is plotted against price received by the recycler (netback). At moderately high solvent prices the recycler would be able to afford a payment to the waste producer. It should also be noted that, at high solvent prices, the deeper recovery option becomes more attractive.

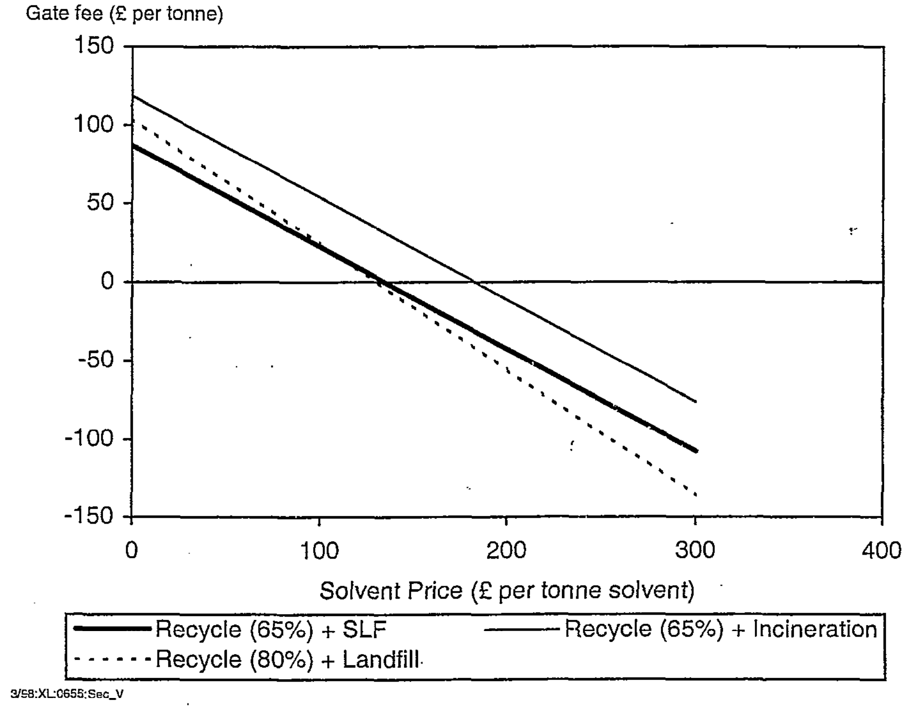


Figure 4.3 Recycler gate fee versus solvent price

4.1.8 Future costs

If costs and prices change in relation to each other in the future, the economic attractions or otherwise of particular disposal routes could alter.

Prices of new solvents will continue to follow the chemical business cycle, which will certainly cause the profitability of recycling to fluctuate. In general, however, the trend prices of many commodity petrochemicals are forecast to decline slowly in real terms over time. This reflects reductions in production costs resulting from improvements in process efficiencies and increasing plant size. Economies of this sort may be more difficult to achieve for recycling plants because of the batch nature of the recovery process, and the limited feedstock sources. On the other hand, operating costs such as labour might be expected to increase slowly in real terms. For several solvents, there may therefore be a marginal decline in profitability over a decade, but this will be overshadowed by usual variations over the business cycle.

The price of SLF will remain within the range of a credit of the avoided cost of other kiln fuels and a debit of the alternative disposal route for the waste producer. Supply and demand may affect the price in the longer term. At present, however, the sale of SLF seems to be linked to formulae rather than pricing as a commodity in a free market. This reflects the degree of commitment on both sides and the need for reliable supply of a tightly specified material.

Supply and demand will be the major factor in determining incinerator prices. Where there is competition for wastes, such as with SLF, the incinerators might need to drop the gate fee. The main question, however, is whether pressure will be increased to move wastes away from landfill. This would increase demand for incineration, for which additional capacity might be needed.

The future relationship of the cost elements is therefore difficult to predict as it is contingent on several factors. Some of these factors, relating to supply and demand, are reviewed in Section 4.2.

4.2 Waste Supply and Disposal

4.2.1 Aim

The main topic of interest is whether the blending of organic waste into SLF has deprived recycling or incineration of feedstocks, or will do so in the future. The quantity of SLF for cement kilns has risen to around 70 000 to 80 000 tons per year since the first authorisations. A further quantity is used in lime kilns, which is not covered here.

The following indications have been compiled to assist in answering this question. However, insufficient information is available for a fully accurate analysis.

4.2.2 Solvent Recycling

Table 4.2 indicates the quantities of feedstock processed by the member companies of CORA (Chemical and Oil Recovery Association). The data are for 1990 to 1994. CORA compiles the data on an occasional basis and has not supplied more recent information.

Table 4.2 **Solvent processed by CORA members 1990-94 ($000m^3$)**

Feedstock	1990	1991	1992	1993	1994
Hydrocarbons	49	58	62	42	32
Oxygenated solvents	70	38	45	41	73
Halogenated solvents	15	12	11	5	11
Other solvent mixtures	27	23	17	39	50
Total	161	131	135	127	166

Source: CORA, IAL Consultants.

The CORA member companies typically account for around 75 to 80 percent of total merchant throughput.

The data do not cover the full period in which SLF was introduced, so conclusions on the extent of "poaching" by SLF cannot be drawn. However, it is apparent that the volumes of waste processed vary significantly year on year. There is a drop of over 20 percent between 1990 and 1991. Assuming that the reporting basis is the same for all years, there would appear to be fluctuation in quantities driven by factors other than SLF. It would be hard to demonstrate real trends in these circumstances.

Section 5.1 covers economics. It seems highly unlikely on economic grounds that recyclable single solvent wastes will be blended into SLF. It is also unlikely that recyclable mixed solvent streams would be blended into SLF. However, the residues from recycling certainly are blended into SLF and this confers an advantage if the alternative disposal route is costly. One SLF blender reports (in confidential information) a significant increase in solvent recycled since 1994. This commercial advantage means that recyclers associated with SLF blending can charge a lower gate fee than some of their competitors

4.2.3 Incineration

It is apparent from the review of economics (Section 4.1) that SLF blenders can take wastes at a lower gate fee than incinerators wish to charge. There have been reports of incinerator prices for high calorific value wastes dropping to £20 to £35 per tonne in 1996, and incinerators running at below capacity.

Table 4.3 shows data on the throughput of merchant incinerators in the UK: Rechem, Cleanaway and Leigh (now SARP UK).

Table 4.3 Waste incinerated in UK (000 tonnes)

	1995	1996	1997[(1)]
Waste incinerated	118	135	150[(2)]

[(1)] Estimate.
[(2)] Includes 15 000 tons of meat and bone meal from BSE cull.

As with recycling, there are several factors that might affect incinerator demand, including the restrictions against import and export of waste.

Both Rechem and Cleanaway supplied to Chem Systems a confidential breakdown of the wastes entering their incinerators in 1997. The material is a very varied mixture, ranging from contaminated water and inorganic acids to conventional solvent type wastes. Significant numbers of waste types are relatively high calorific value solvent wastes that could be a potential blendstock for SLF.

The incinerator operators do not identify a systematic change in the composition of their feed waste streams in recent years. However, as it is necessary to maintain a suitable burn menu to run economically, this is what would be expected. If high CV material becomes scarce then the incinerator needs to increase gate fee to allow for fuel costs or, if this is commercially not feasible, burn less waste.

Incinerator operators can cite examples of specific consignments that have been taken by SLF blenders rather than incinerators. It is difficult to demonstrate any shift on a macro-scale without the confusion of other factors. The incinerator market has reportedly picked up recently, aided by the need to incinerate cattle waste from the BSE cull.

4.2.4 Future trends

The trends of relevance to SLF and other disposal routes fall into several categories:

- waste arisings
- regulatory drive
- cement industry
- waste treatment capacity.

Waste arisings

There are regulatory and market pressures to encourage minimisation of waste quantities and for environmentally friendly products.

In several solvent applications, the move to low-solvent, aqueous or dry systems is well established. This applies to formulated products such as coatings, inks, adhesives and agrochemicals. The shift is also apparent in surface cleaning and electronics. This trend will continue where technically feasible.

There is also current pressure to reduce emissions of VOCs (Volatile Organic Compounds), including in solvent applications. Companies may choose to retain solvent-based systems and introduce abatement. The abatement techniques may be containment, destruction, or recovery from the air stream. If recovery is used, it is even possible that the quantities of dirty solvent requiring recycle could increase.

The use of some solvents, particularly chlorinated products, is likely to decline in some areas because of health or environmental concerns and perceptions.

Non-solvent wastes include those from processing operations, such as distillation residues. Producers will minimise these for economic reasons as well as to satisfy regulatory pressures. There will be notable exceptions to this trend, arising from expansion of plants. A further factor could occur if Inspectors classify more by-product streams as wastes, which could place more waste into the external disposal market.

Waste oils are a large source of organic wastes (see Section 2.3). There is no reason to anticipate a decline in the quantity of waste oils produced from transport-related sources.

The quantities of wastes are not well established, so it is not possible to forecast arisings. Chem Systems' judgement on broad trends is summarised in Table 4.4. Trends in solvent use are based on market analysis for new solvents in Western Europe. Waste minimisation possibilities are based on quoted achievements and targets in the industry world-wide. Arisings of oil wastes are expected to grow broadly with GDP.

The trend data are indicative only, but they suggest a net future decline in the quantities of organics in the UK wastes that might be candidates for SLF.

Table 4.4 Indicative trends in future waste arisings to 2005

	Average Growth, % pa
New Solvent:	
Hydrocarbons	(2.0) – (3.5)
Oxygenates	(0.5) – (1.5)
Chlorinated	(5.0) – (8.0)
Solvent Wastes:	
Hydrocarbons	(1.5) – (3.0)
Oxygenates	0 – (1.0)
Chlorinated	(3.0) – (6.0)
Chemical Process Wastes	(2.0) – (3.0)
Fine Chemical Wastes	(3.0) – (4.0)
Waste oils	1.5 – 2.5

Note: Data in (brackets) are negative

Regulatory drive

Environmental regulations and their enforcement will affect whether certain wastes are directed to specific disposal routes or excluded from them.

The intentions of the EU landfill directive and the policy of the Environment Agency will make landfill unavailable as a disposal route for most liquid wastes containing organic compounds. It is difficult to predict the effect of this without accurate data on the quantities of wastes that are currently inappropriately landfilled.

In the context of industrial organic wastes, financial measures like landfill tax would probably be insufficient to have significant impact. The regulatory enforcement of controls on waste disposal will provide the mechanism for change. Comparison with estimates of incinerable wastes in Germany, for example, suggest that the quantities requiring incineration in the UK could increase significantly.

The quantities of materials permitted to be blended into SLF are another regulatory driver, as is the limit on substitution of conventional fuels.

Cement industry

The future possible consumption of SLF by cement kilns depends on three factors:

- growth in cement production
- changes in energy efficiency

- producers' wish to substitute fuels.

Cement is a mature industry. The demand is very heavily dependent on construction activity. The production peaked at around 17 million tons in 1989 and has recently been around 13 million tons per year. The cycles cannot be predicted with any confidence. The trend growth is likely to be low, at around one to two percent per year.

The energy efficiency of the kilns is very dependent on the type of process, and this is strongly influenced by the characteristics of the feedstock supply. Chem Systems understands that rationalisation in the number of plants is likely to continue, and that new plants with wet feed may be semi-wet processes rather than wet. The average energy consumption in UK kilns decreased from around 7.5 GJ/tonne clinker in 1961 to around 4.4 GJ/tonne in 1991. This trend is expected to continue to some extent.

The producers are not necessarily committed to the maximum possible substitution of usual fuels with SLF. There are product quality issues to be addressed, and stringent environmental requirements relating to the SLF composition. In addition, as noted in Section 2.3, there are other waste-derived fuels such as tyres and plastics that can be used.

The potential demand for SLF, based on current capacities and processes, is shown on Table 2.12. Even allowing for some improvement in energy efficiency and the supply of other wastes, there is a potential maximum demand for SLF well in excess of 400 000 tons per year.

Waste treatment capacity

The economics of solvent recycling, combined with a probable slow decline in waste arisings, mean that recycling capacity is likely to be in place to satisfy UK demand.

Incinerator capacity is more difficult to predict. However, at least one merchant incinerator is considering expansion of hazardous waste incineration capacity. Provided that the wastes are directed by regulation to incineration, pricing of disposal must adjust in the marketplace to support reinvestment.

Overview

The arisings of several categories of organic wastes should tend to diminish in coming years because of environmental pressures. Landfill is likely to be excluded as a disposal route in many instances, so that the quantities of wastes for incineration or SLF are expected to increase.

The maximum quantity of SLF that could be used in cement kilns is very significant compared to the current merchant incineration market, and could cause distortion of pricing or other factors. On present indications, it is unlikely that current producers will choose to maximise the use of SLF to this extent.

5. SUMMARY AND CONCLUSIONS

5.1 General

This section of the report is a succinct summary of the findings of the study into the use of Substitute Liquid Fuels (SLF) in cement kilns.

It covers:

- sources of waste that could be blended into SLF
- a Life Cycle Assessment (LCA) on the use of SLF
- a commentary on economic and market issues
- conclusions and possible criteria for exclusion of wastes from SLF.

5.2 Waste Streams

Types

The waste streams that are used in SLF, or are potential sources of SLF, fall into several main categories.

- Solvent wastes arise from many sources, including fine chemical production and the industrial application of products that contain solvents, such as coating, adhesives, metal cleaning and others. In practice, a large part of the solvent wastes is sent to recyclers. The residues from recycling is a significant category of SLF waste. Most of the existing SLF blenders are also recyclers.

- Non-solvent arisings, primarily from the chemical industry, include by-products, reagents, feedstocks and process wastes. This covers a very wide range of compounds. One chemical by-product, from an adipic acid plant, is a major SLF stream.

- Used lubricating oils and similar are extensively fed to cement kilns in Germany. Other disposal routes are used in the UK, but this is a possible contributor to SLF.

- Many wastes are classified as oily wastes in the Environment Agency's developing database. Total quantities are large, but insufficient information is available to determine whether this too could be a source of SLF.

Compositions

The Environment Agency imposes very tight specifications on the SLF blend that is supplied to each cement kiln that uses it. However, the compositions of the wastes that are blended into SLF vary widely, even when from similar sources. This suggests that any criteria for excluding wastes from SLF must be based on composition and properties, not waste source.

The following variations in composition are observed.

- Wastes range from substantially all organic compounds to very dilute washings with no calorific value.
- Halogen content can exceed 50 percent, as in some metal cleaning wastes. Heavily brominated streams, or those with iodine, are not reported in SLF, perhaps because of difficulties with plume colour. The limits set by the Environment Agency for blended SLF are strict for iodine in particular.
- Metal content is often not analysed in individual wastes. The streams with the highest disclosed metal contents are those containing pigment, primarily coating waste, and recycling residues.
- Very diverse organic compounds are reported. It should be noted that blenders (and cement kilns) have guidelines which exclude substances with potential hazard risks for workers or with particular environmental problems, such as PCBs.

Quantities

Estimation of quantities of organic wastes is difficult because of the vary scattered nature of the arisings. A broad estimate is presented in Table 5.1; more accurate analysis will become possible as the Environment Agency's database is developed in the future.

Table 5.1 Summary estimate of quantities of selected organic wastes in the UK, 1997

Waste type	Quantity *(000 tpa)*	Comment
Chemical industry: non-solvent	250 - 350	Includes on-site residues
Chemical industry: solvent wastes	60 - 90	
Paints, coatings	90 - 130	Part to recyclers
Surface cleaning etc	25 - 30	Part to recyclers
Other solvent users	35 - 55	Part to recyclers
Recycling residues	50 - 70	
Lube oils etc	220 - 250	Other disposal routes
Other oily wastes	500 - 600	Other disposal routes
Net Total (2)	**1 100 -1 350**	
Gross Total (1)	**1 185 -1 505**	

(1) All wastes but not recycling residues

(2) Allowing for solvent wastes sent to recyclers : only the residue added in

5.3 Life Cycle Assessment

The Life Cycle Assessment (LCA) is intended to show the difference in environmental burdens arising from various ways of disposing of organic wastes. The disposal routes compared in the study are high temperature incineration, use of SLF in cement kilns, and solvent recycling. Landfill and discharge to sewer or surface water are not considered as legitimate disposal options: for economic reasons, waste components would not be sent to incineration, for example, in preference to landfill unless regulations required it. To permit an analysis to be made of the influence of different components in the waste, the LCA was performed for a number of wastes representing a range of specified compositions.

Blending organic wastes into SLF and burning in cement kilns is preferable to disposal by incineration for most of the parameters considered in the LCA. This is largely because the SLF is replacing conventional cement kiln fuels, coal and petroleum coke. Both cement kilns and high temperature incinerators are very effective ways of disposing of organics in terms of destruction efficiency, and containment of secondary pollutants such as acid gases and metals.

Although the cement kiln route is preferable to incineration for almost every parameter, there are possible exceptions. From available data, it seems likely that the containment of hydrogen halides is more complete on an incinerator (fitted with specific abatement) than in a cement kiln which relies on the alkalinity of the raw materials. Volatile and semi-volatile metals may follow this pattern too. However, it should be noted that to provide a definitive analysis, a component mass balance is necessary, and there is uncertainty and variability in available data. Nevertheless, most data suggest that metal compounds are released only at very low concentrations, and halogen compounds at low concentrations.

Recycling

The evaluation of solvent recovery and recycling is complex as the analysis is different for every solvent compound. However, the following conclusions are drawn from the analysis.

- Recycling is preferable to incineration on almost every count.

- Recovery of a high percentage of solvent, to leave a dry residue, is environmentally preferable to 60-70 percent recovery with incineration of residues.

- Recycling is not necessarily environmentally preferable to the SLF route. This depends on the solvent type. The comparison between recycling and SLF shows trade-offs in some areas.

The comparison of disposal routes for a typical oxygenated waste is shown on Figure 5.1. The figure shows selected burdens for systems including SLF used in cement kilns and recycling, expressed as a percentage of burdens from a system including incineration of the subject waste.

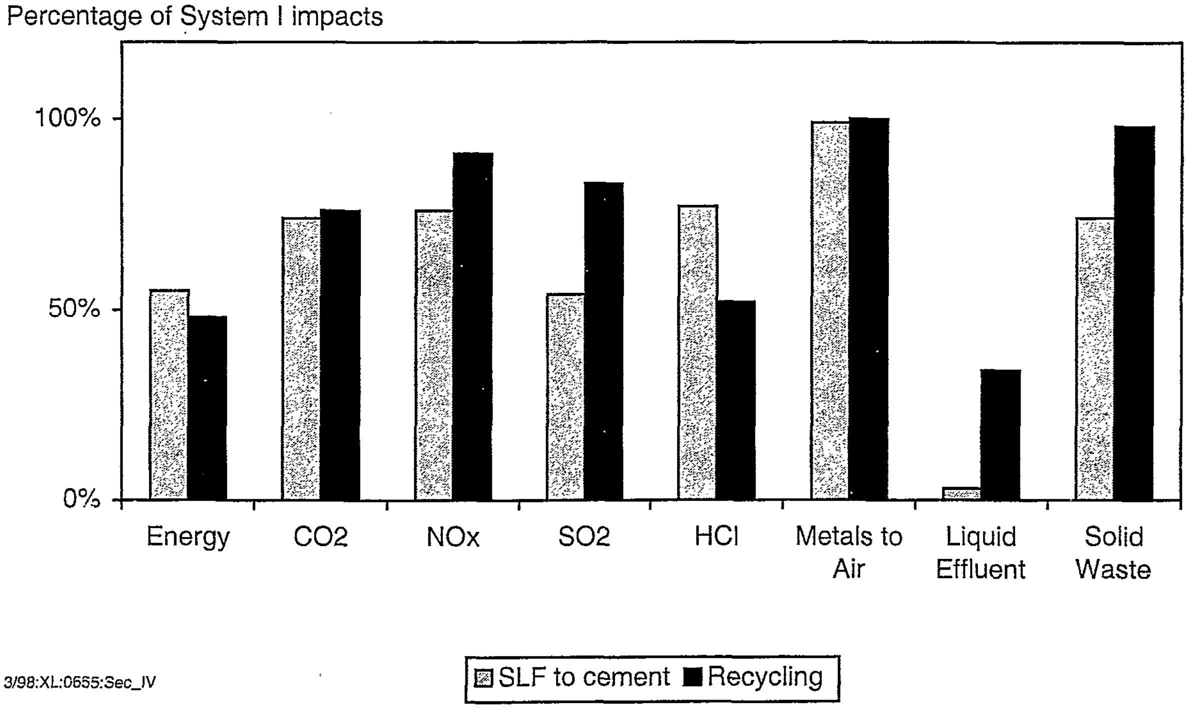


Figure 5.1 **Impacts as percentage of incineration impacts: oxygenated solvent**

Variation in composition

The LCA was performed for several different wastes. The results indicated the following.

- With very dilute wastes, the advantage of sending wastes by the SLF route is small or even negative.
- Highly halogenated wastes are likely to result in greater loss of hydrogen halides from a cement kiln than from an incinerator.
- The same probably applies to volatile and semi-volatile metals, although data are not clear.
- Dioxin emissions are similar and small for cement kilns and incinerators.
- The advantage of recycling is weakest where the solvent has a high energy content and new solvent is manufactured in a relatively low-burden process.

5.4 Economic and Market Issues

Sending waste by the SLF-to-cement kiln route is significantly cheaper than disposal by a merchant hazardous waste incinerator. This suggests that SLF is capable of poaching certain wastes from incineration, at the incinerator operator's preferred pricing structure. Where the incinerator pays a credit for high energy solvent wastes, using them as support fuel, the ability of SLF to poach wastes is considerably reduced.

The economic analysis also indicates that solvent recycling is more economically attractive than sending the waste to SLF, particularly when single solvent streams are recovered rather than "thinners". For single solvent streams, with the exception of relatively cheap methanol, it is also attractive to recover as much solvent as possible, leaving a dry residue. The economic case is not as clear when deep recovery (80 percent) of thinners is considered; this options appears similar to recovering around 65 percent of feed waste and sending the residue to SLF.

The economic analysis indicates that it is plausible that SLF could attract wastes away from incineration. The incinerator operators have not identified a systematic change in quantities incinerated or average composition in recent years that might support this. The possibility remains a long term concern, however.

Similarly, there is no firm evidence that SLF is taking materials from the solvent recycling loop. In this case, as noted above, the economic incentive appears to favour recycling in any case.

The quantity of organic waste that could potentially be consumed by cement kilns in the UK is very large, as Table 5.2 indicates.

Table 5.2 Maximum SLF consumption in cement kilns

Cement kilns	**Substitution** *(%)*	**SLF use** *(000 tpa)*
Authorised/trials (October 1997)[1]	Various	215
All except those with tyre/plastic burning interest	25	340
All except those with tyre/plastic burning interest	40	540
All kilns	40	840

[1] Ketton is included in this.

Compared to the quantity of waste arisings estimated in Table 5.1, this is potentially a significant distortion in the waste disposal business. It is unlikely, on present indications, that cement kiln operators will choose to maximise the use of SLF to anything approaching these figures.

5.5 Criteria for Exclusions

The use of SLF in properly controlled cement kilns is an environmentally favourable disposal route. While the environmental burdens arising from burning SLF in the kiln are similar to those from burning it in hazardous waste incinerators, the advantage gained by substituting coal and petroleum coke in the cement kiln is significant.

Solvent recycling is also beneficial, with advantages that are different for streams of various compositions. Economic analysis suggests that recycling will occur in preference to disposal as SLF. It is therefore not appropriate to attempt to exclude wastes from SLF (or incineration) by some definition of what is recoverable.

If it is required to exclude specific individual wastes, then the criteria could be:

- wastes of significantly worse quality than usual cement kiln fuels, so there is a disadvantage in blending in SLF
- wastes of very low calorific values, for the same reasons
- wastes with a high halogen content, because incineration offers better retention (on available data)
- wastes with high concentrations of volatile or semi-volatile metals, for the same reason
- wastes for which combustion processes may not be ideal, such as those with very high metals contents or ash contents.

Suggestions are presented in Table 5.3 of possible restrictions on the composition of individual wastes being blended with SLF. There is no rigorous methodology underlying the suggestions of composition limits. Instead, the limits reflect the results of the LCA, with the intention of excluding heavily chlorinated wastes, for example. Attention has also been paid to be data available on individual waste compositions to ensure that levels are realistic. Reference has also been made to the existing specifications for blended SLF.

Table 5.3 Possible exclusion limits for individual wastes being blended to SLF

	Unit	**Limit (maximum unless noted)**
Calorific value (LHV)	MJ/kg	3.0 (minimum)
Sulphur	g/MJ	1.5
Nitrogen	g/MJ	1.5
Any halogen	g/MJ	4.0
Total halogens	g/MJ	6.0
Ash	g/MJ	25.0
Mercury	mg/MJ	2.0
Thallium	mg/MJ	2.0
Total mercury plus thallium	mg/MJ	3.0
Cadmium	mg/MJ	10.0
Total semi-volatile metals(1)	mg/MJ	75.0
Total metals	mg/MJ	350.0

Note: (1) See definitions in Section 4.2.2(b)

All the restrictions imposed by the Environment Agency on the blended SLF should still apply. These are rather more stringent than those in place in several other countries where SLF is used in cement kilns.

The consequences of the limits suggested on Table 5.3 would be:

- exclusion of substantially aqueous wastes, which arise in just about every industry sector as washings etc

- exclusion of heavily halogenated streams, which would be certain streams such as, for example:

    - waste solvents from fine chemical production
    - waste tars from fine chemicals production
    - solvents from surface cleaning
    - solvents from adhesive applications

- exclusion of wastes with higher metal contents than typically found in wastes currently blended into SLF; likely sources are:

    - coatings waste with high metallic pigment content, such as from the automotive industry

    - residues from solvent recycling.

One final question is whether it is necessary to exclude individual wastes when the blended SLF would be of satisfactory quality. Separate waste water streams are often combined on site before treatment or discharge, for example. This may make treatment technically possible, by diluting material toxic to biomass, but there may be an element of simple dilution. It is a policy decision as to whether exclusion of certain wastes from SLF is necessary or administratively feasible.

BIBLIOGRAPHY

ASSOCIATION TECHNIQUE DE L'INDUSTRIE DES LIANTS HYDRAULIQUES: The French Experience on Co-Combustion in Cement Kilns, DGXII Workshop, 1997

BOUSTEAD, I Dr, A report for the Association of Plastics Manufacturers in Europe (APME), Eco-profiles of the European Plastics Industry, Various Reports 1993-1995

BRITISH CEMENT ASSOCIATION: UK Cement Manufacture and the Environment

CIMENT D'OBOURG SA, Waste Co-processing in Industry, 1996

CLEANAWAY: The Responsible Incineration of Hazardous Waste

CONCAWE: Report 1/95 Oil Refinery Waste, Disposal methods, Quantities and Costs 1993

CONCAWE: Report 5/96 Collection and Disposal of Used Lubricating Oil, 1996

ENVIRONMENT AGENCY: Report of the Substitute Fuels Trials Assessment Panel ..... (relating to)...... Kiln 4 at Rugby Cement, Barrington, October 1995

ENVIRONMENTAL AGENCY: The use of Substitute Liquid Fuels in Cement Kilns – Progress Report from the Environment Agency to the House of Commons Environment Committee, October 1997

ENVIRONMENTAL TOXICOLOGY INTERNATIONAL: All Fired Up – Burning Hazardous Waste in Cement Kilns, 1992

ETSU: Waste Combustion in Cement Kilns, ETSU B/EW/00497/27/REP; Contractor – McLellan

EURITS: Methodology for the Determination of Technical Co-incineration Criteria, 1996

EURITS: The Incineration of Hazardous Waste, 1997

EVANS P, Croda Hydrocarbons: 100 percent Recycling, the First Option (paper)

IAL CONSULTANTS: Industrial Solvents Recycling in the UK, 1996

IPC GUIDANCE NOTE S2 3.01: Cement Manufacture, Lime Manufacture, and Associated Processes, 1996

SCHNEIDER M: The Environmental Impact of Co-combustion in Cement Kilns, Belgirate, 1997

STATISTISCHE BUNDESAMT, Germany: Fachserie 19, Reihe 1.2, Abfallbeseitigung im Produzierenden Gerwerbe und in Krankenhäusern, 1993

TECHNICAL GUIDANCE NOTE (ENVIRONMENTAL) E1: Best Practicable Environmental Option Assessments for Integrated Pollution Control

ZEEVALKINK Dr J A.; ALKEMADE Mrs M M C, The Materials and Energy Potential Method for the Quantitative distinction between Valorization and Elimination in the Cement Industry, TNO-MEP-R96/302, 1996.