“Environmental Benefits of Using Alternative Fuels in Cement Production”

A LIFE-CYCLE APPROACH

CEMBUREAU

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The Association acts as spokesman for the cement sector towards the European Union institutions and other authorities, and communicates the industry's views on all issues and policy developments likely to have an effect on the cement market in the technical, environmental, energy and promotion areas. Permanent dialogue is maintained with the European and international authorities and with other International Associations as appropriate.

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CONTENTS

— Page —

1	**INTRODUCTION**	**4**
1.1	Preamble	4
1.2	Policy Background	4
1.3	This Report	5
2	**CARBON DIOXIDE REDUCTION AND STABILISATION**	**5**
2.1	Issues	5
2.2	Strategy 1: Improving the Efficiency of Cement Kilns	6
2.3	Strategy 2: Use of Alternative Fuels	6
2.4	Strategy 3: Substitution of Raw Materials	7
2.5	Conclusions	7
3	**DISPOSAL VERSUS RECOVERY IN CEMENT KILNS**	**7**
3.1	Introduction	7
3.2	System Definition	8
3.3	Environmental Impacts	9
4	**RECYCLING VERSUS RECOVERY IN CEMENT KILNS**	**13**
4.1	Introduction	13
4.2	Recycling Versus Utilisation of Waste Plastics	13
4.3	Recycling Versus Utilisation of Waste Oils	14
5	**SUMMARY OF ENVIRONMENTAL BENEFITS**	**15**

1. INTRODUCTION

1.1 Preamble

The principle of sustainable development has been accepted as a central policy objective of the European Union. The European cement industry, through CEMBUREAU, has engaged in proactive and positive debate with decision makers on how the industry can best put these principles into practice.

Hitherto, decision making in the environmental arena has tended to be on a piecemeal basis whereby each industrial sector's resource needs, energy requirements and environmental impacts of each pollutant were considered individually. CEMBUREAU believes this approach fails to maximise opportunities for general environmental improvements, nor does it provide an adequate framework for the optimisation of the costs and benefits of policy options. In its place, CEMBUREAU advocates a holistic, integrated view of industrial activity and the environment. Using this broader concept, the present report explores one facet of sustainable development: namely, how the European cement industry can contribute towards the implementation of the Community Strategy for Waste Management by substituting conventional fossil fuels with alternative and suitable waste materials. Using a life cycle approach, the report demonstrates the overall environmental benefits that fuel substitution can deliver when the cement industry participates as a legitimate player within the Community's waste management infrastructure.

The use of waste in European cement kilns saves fossil fuels equivalent to 2.5 million tonnes of coal per year.

1.2 Policy Background

The cornerstone of current European policy in the environmental arena is the Treaty on European Union, signed in February 1992 at Maastricht and ratified in 1993. The key issues of relevance to the cement industry arising from the Treaty are as follows:

(1) Sustainable growth in Europe, respecting the environment, is established as a principal objective of the European Union.

(2) Integration of environmental imperatives into other areas of policy is seen as another key requirement.

(3) Flexibility in decision making is promoted, with decisions being taken at Community level if objectives cannot be appropriately met at Member State level.

The European cement industry fully endorses these goals and, through CEMBUREAU, is actively engaged in assessing the contribution it can make towards achieving these goals.

With respect to waste management, in 1997 the European Commission published a review of the Community Strategy for Waste Management originally established in 1989. The review endorses the concept of sustainable development and the principles of the waste management hierarchy, namely:

- prevention of waste;
- recovery of waste (including material recycling and energy recovery);
- safe disposal of waste;
- application of the proximity principle and self-sufficiency in waste management outlets.

CEMBUREAU concurs with the principles embodied in the waste management hierarchy, which rightly places waste prevention and recovery/reuse in a pre-eminent position relative to ultimate disposal. CEMBUREAU believes that every opportunity should be explored to prevent and minimise waste generation and to maximise its recovery and reuse.

The utilisation of wastes in the cement industry, principally as alternative fuels but also as supplementary raw materials, is compatible with the general principles of waste management at both European Union and national levels, and with existing EU and national policies on energy efficiency, climate change and waste management. There are two reasons why the use of such materials is considered by the industry to be fully compatible with the principles of sustainable development:

(1) In terms of the *cement manufacturing process*, the use of alternative fuels and raw materials has the potential to reduce emissions to the environment relative to the use of conventional fossil fuels, and conserves non-renewable resources.

(2) In terms of the *waste management system*, cement kilns offer a safe alternative to conventional disposal of waste in dedicated waste incinerators or in landfills, again resulting in overall benefits by reducing environmental burdens and reducing the need for dedicated treatment capacity.

These two aspects of waste management are interlinked. They are best examined by the technique known as Life Cycle Assessment (LCA). An LCA describes the impact on the environment during the stages a product goes through from the time the raw materials are obtained until the final disposal of the product.

1.3 This Report

In this report LCA techniques are used to examine two related topics:

(1) The production of cement by the use of two different types of fuel: coal, and non-fossil fuels made from waste.

(2) The management of waste by two different routes: utilisation in cement kilns, and disposal or reuse by other operations.

The environmental benefits of utilising waste materials in cement kilns is examined under three headings:

- climate change and carbon dioxide reductions;
- disposal versus recovery in cement kilns;
- recycling versus recovery in cement kilns.

Information under the last two headings is based on studies carried out by TNO (The Netherlands) and the Fraunhofer Institute (Germany).

2. *CARBON DIOXIDE REDUCTION AND STABILISATION*

2.1 Issues

The European cement industry is already recognised as being highly energy efficient, and additionally there is little scope for technological changes which will reduce emissions of carbon dioxide from the production process. <u>However, the industry has demonstrated that the substitution of conventional fossil fuels with alternative fuels based on waste can make an important contribution to sustainable development through the reduction of the global burden of greenhouse gases such as carbon dioxide</u>.

The manufacture of cement is an energy intensive operation, and the cost of energy represents a significant part of the total production costs. On an EU wide basis, cement production totals approximately 170 million tonnes per year. With an average energy consumption equivalent to the combustion of 120 kg of coal per tonne of cement, this level of production utilises the equivalent of 20 million tonnes of coal.

During the manufacture of cement, CO_2 is generated from three sources:

- combustion of fuel in the kiln, to maintain the required kiln temperature;
- decarbonation of limestone within the kiln;
- use of electricity in installations such as grinding mills.

A total of 0.83 tonne of CO_2 is emitted per tonne of finished product (80% clinker), and is made up as follows:

- CO_2 from decarbonation is **0.45 tonne** per tonne of cement;
- CO_2 from the combustion of coal is **0.28 tonne** per tonne of cement;
- electricity produced in coal fired power plants to operate on-site installations contribute a further **0.1 tonne** of CO_2 per tonne of cement.

Of the three sources, the decarbonation of limestone generates the greater proportion (60%) of the CO_2 emissions liberated from the kiln. It should be noted that these three sources of emissions are essentially independent of each other.

<u>There are three main strategies by which the cement industry may contribute to a reduction in CO_2 emissions</u>:

<u>(1)</u> Improve the energy efficiency of cement manufacture;

<u>(2)</u> Substitute fossil fuels used in cement kilns by fuels derived from waste;

<u>(3)</u> Modify the composition of cement by using cement constituents which require less energy to produce than cement clinker.

Each strategy is discussed below.

2.2 Strategy 1: Improving the Efficiency of Cement Kilns

Dealing first with Strategy 1, emissions of CO_2 from cement kilns are closely linked with process and energy efficiency. Over the past four decades, the European cement industry has adopted a policy of continuous improvement in plant, equipment and operation. For example, less efficient kilns are being replaced by more fuel-efficient preheater and precalciner kilns and ball mills for cement grinding have been replaced by more efficient grinding systems. Presently, 78% of Europe's cement production is from dry process kilns, 16% is from semi-dry or semi-wet kilns, and only 6% is from wet process kilns mainly in geographical areas with wet raw materials. These and other energy efficiency measures adopted within the industry have resulted in significant reductions in fuel use, and hence of CO_2 emissions.

The industry will continue along the same lines to further improve energy efficiency. There is, however, now limited scope for further improvements in energy efficiency, although the ongoing programme of modernisation will continue to result in lower CO_2 emissions per tonne of cement produced.

2.3 Strategy 2: Use of Alternative Fuels

This leads directly to Strategy 2, and the use of alternative fuels in cement kilns. This practice has a wider benefit than merely reducing CO_2 emissions at the point of cement production. <u>The global CO_2 emissions are reduced, but the reductions occur in other industry sectors than the cement industry</u>. To analyse the benefits of the use of alternative fuels in cement kilns, we have applied LCA techniques to two scenarios:

(1) *Scenario 1:* Waste is combusted in a dedicated incinerator, with energy recovery, and the power generated is fed into the national electricity grid system. The cement kiln operates with a conventional fossil fuel, coal.

(2) *Scenario 2:* Waste is transferred to the cement kiln, displacing an amount of coal in proportion to its heat content. Since the incinerator is no longer operational, the electricity it originally produced is now generated by a coal fired power station.

For each scenario, we have calculated the burden of CO_2 to atmosphere, and then compared the two scenarios for the net effect on CO_2 emissions. The calculations are presented in *Annex A*.

The net CO_2 burden of the two scenarios is obtained by subtracting the total burden of *Scenario 2* from the burden of *Scenario 1*. <u>The benefit (reduction) in CO_2 emissions from burning waste in cement kilns as opposed to dedicated incinerators is summarised in *Table 1* and *Table 2*</u>.

Table 1 Summary of CO_2 emissions from burning 1 tonne of waste in a dedicated incinerator with energy recovery or in a cement kiln, discounting the baseload operation of the power plant

Activity	Biofuel (16 GJ/t)	Solvent Waste (26 GJ/t)
Incineration in dedicated incinerator	3,379 kg CO_2	4,429 kg CO_2
Combustion in cement kiln, displacing coal	2,778 kg CO_2	3,462 kg CO_2
Net benefit due to combustion in cement kiln	601 kg CO_2/t waste	967 kg CO_2/t waste

The above analysis covers operating practice observed by many incinerators in the EU: namely, the recovery of energy alongside the waste destruction process. However, there remain some incinerators which have no heat or energy recovery facilities. In this case, the power plant is effectively decoupled from each of the scenarios. The net reduction in CO_2 emissions when waste is combusted in the cement kiln is greater, as shown in *Table 2*.

Table 2 Summary of CO_2 emissions from burning 1 tonne of waste in a dedicated incinerator without energy recovery or in a cement kiln

Activity	Biofuel (16 GJ/t)	Solvent Waste (26 GJ/t)
Incineration in dedicated incinerator	3,379 kg CO_2	4,429 kg CO_2
Combustion in cement kiln, displacing coal	1,760 kg CO_2	1,820 kg CO_2
Net benefit due to combustion in cement kiln	1,619 kg CO_2/t waste	2,609 kg CO_2/t waste

By burning waste in a cement kiln and substituting for coal, a non-renewable resource, savings are made through resource conservation and associated CO_2 emissions. The cement kiln also makes more efficient use of the intrinsic energy of the waste material. Specialist waste incinerators are very inefficient converters of the heat content of wastes, whereas a cement kiln approaches 100% efficiency. A net decrease in the quantity of CO_2 released, relative to a scenario in which waste is combusted in a dedicated incinerator, reduces the environmental impact of the greenhouse effect during the combustion of wastes.

2.4 STRATEGY 3: SUBSTITUTION OF RAW MATERIALS

The use of materials such as pulverised fly ash or slag to replace raw materials such as clay in cement kilns has the potential to reduce CO_2 emissions at the point of cement production, as these products use less energy than clay.

A much more efficient way of using industrial by-products and natural materials is to mix these with cement clinker and grind both materials to a cement. Such cement consequently consists of cement constituents other than ground clinker. The additional cement constituents often provide additional beneficial properties to the cement. The modification of the cement composition by the usage of additional cement constituents results in considerable reductions in CO_2 emissions as not only fuel related CO_2 is reduced but also the process related CO_2 (decarbonation).

2.5 CONCLUSIONS

<u>The analyses demonstrate the clear benefits the cement industry can provide in CO_2 reduction through integrating cement kilns within an overall waste management strategy, either through the use of alternative fuels, or through the use of materials such as industrial by-products as additional cement constituents</u>.

3. DISPOSAL VERSUS RECOVERY IN CEMENT KILNS

3.1 INTRODUCTION

<u>LCA techniques have been used to compare the environmental effects of processing the following wastes in a cement kiln as opposed to destruction in dedicated waste incinerators specially designed for each waste type</u>:

- spent solvents (in a rotary kiln incinerator);
- filter cake (in a rotary kiln incinerator);
- paint residues (in a rotary kiln incinerator);
- sewage sludge (in a fluidised bed incinerator).

The project was commissioned by the Dutch Government as part of their analysis of the Dutch National Hazardous Waste Management Plan 1997 - 2007, and was undertaken on their behalf by the Netherlands Organisation for Applied Scientific Research (TNO)[1)].
Two methods of allocation were constructed. The first method treated the cement kiln and dedicated waste incinerators as isolated units, and apportioned emissions and their environmental effects solely to the function of waste processing. In other words, upstream and

1) • *Tukker A (1996). LCAs for Waste: The Dutch National Waste Management Plan 1997-2007. Paper presented at the 4th Symposium for Case Studies, SETAC Europe, Brussels, December 1996.*
• *Keevalkink J A and Hesseling W F M (1996). Waste Processing in a Wet Cement Kiln and a Specialised Combustion Plant. Report No. TNO-MEP-R 96/082, TNO Institute of Environmental Sciences, Energy Research and Process Innovation, Apeldoorn, Netherlands.*

downstream operations such as coal mining and transportation (in the case of the cement kiln) and electricity generation (in the case of the dedicated incinerator) were not considered, nor were the avoided burdens resulting from fuel substitution in the cement kiln. However, it was realised that this method of allocating environmental effects penalised waste processing, since emissions from cement kilns are regulated separately to those from dedicated incinerators, with higher emissions of acid gases such as sulphur dioxide being permitted in cement kiln operation due to the fact that they are associated with the raw materials. Further, the wider implications of fuel substitution could not be assessed.

The alternative method of system enlargement was therefore agreed with the Dutch authorities and applied to the LCA. Conceptually, this method is identical to that described in *Section 2* for the assessment of CO_2 emissions during the burning of waste, and illustrated in *Figures 1A* and *2A* in *Annex A*. In system enlargement, the additional upstream activity of fossil fuel procurement and the downstream activity of electricity generation are considered in conjunction with the incinerator and the cement kiln operations. The latter is offset with the burden associated with the generation of electricity as a result of the waste being transferred from the incinerator to the kiln, while the incinerator system is offset with the burden of procuring fossil fuel for the cement kiln. The results of the LCA, as applied to the specific case of a cement kiln in Belgium, are discussed below.

3.2 System Definition

The basis of the LCA was one tonne of waste, either incinerated in a dedicated incinerator, or combusted in a cement kiln as a substitute for conventional fuels, in the present case coal (90%) and crude (10%). The inputs and outputs to the two systems are summarised in *Table 3*.

Table 3 Summary of inputs and outputs to the cement kiln and dedicated incinerators

	Dedicated Incinerators	Cement Kiln
Input Materials	• Spent solvents • Filter cake • Paint residues • Sewage sludge	• Spent solvents • Filter cake • Paint residues • Sewage sludge
Input Utilities	• Electricity • Lime • Sodium hydroxide • Ammonia	• Electricity at the kiln • Electricity for waste processing • Transport to kiln
Airborne Emissions	• Acid gases • Metals • CO_2 • CO • Dioxins • Hydrocarbons	• Acid gases • Metals • CO_2 • CO • Dioxins • Hydrocarbons
Waterborne Releases	• Metals in effluent	None (no liquid effluent)
Solid Wastes	• Solid residue • Fly ash • Bottom ash	None (recycled within kiln)
Avoided Products	• Steam • Electricity	• Input coal • Input crude • Input raw material

The system definitions were based on data obtained on actual, operating incinerators in the Netherlands and a wet cement kiln in Belgium. In the incinerator systems, the flue gas is cleaned in a wet scrubber, resulting in a release of liquid effluent from the plant.

Additionally, in the case of the fluidised bed incinerator for sewage sludge, an SNCR deNOx system was installed, necessitating an input of ammonia. Solid residues requiring disposal included fly ash, filter sludge and bottom ash.

In the case of the cement kiln, there was neither a release of liquid effluent nor a release of solid residue, since cement kiln dust was recycled back into the kiln, a practice that is standard in the industry.

3.3 Environmental Impacts

In an LCA, the environmental impacts resulting from the releases to air, water and land from the incinerator systems or the cement kiln are grouped into categories. Each chemical released can contribute to one or more impact categories and conversely an impact category can contain contributions from a number of releases - for example, a release of sulphur dioxide can contribute both to acidification and to human toxicity, while the latter impact category can contain contributions from emissions of acid gases, metals, dioxins, and hydrocarbons. The LCA study focused on the following impact categories:

(1) ***Depletion of mineral raw materials (DRM)***: For the incinerator systems, depletion of raw material results from the use of utilities such as lime. The DRM score can be positive (i.e. the resource is procured and used) or negative (i.e. avoided, when considering net emissions within the overall waste management option).

(2) ***Depletion of fossil energy carriers (EDP)***: This burden relates to the energy input for waste handling and utility input for flue gas cleaning. Again, the net EDP score relative to two different options for waste management can be both positive or negative.

(3) ***Global warming potential(GWP)***: This impact arises from emissions of CO_2 during combustion, and from emissions of methane from biodegradable waste deposited in landfills. Avoiding the generation of energy or avoiding the use of fossil fuels in the cement kiln can result in a significant net avoided GWP score.

(4) ***Depletion of the ozone layer (ODP)***: This impact arises from emissions of volatile hydrocarbons, and is relatively small in magnitude compared to other impacts.

(5) ***Human Toxicity (HT)***: This impact category arises from emissions of acid gases, CO, hydrocarbons, dioxins, metals, etc.

(6) ***Aquatic Ecotoxicity (AT)***: For the incinerator systems, AT results from releases of effluent containing heavy metals. For the fossil fuels, AT arises from effluents generated during the mining or refining processes.

(7) ***Photochemical Ozone Creation Potential (POCP)***: This impact is caused by releases of hydrocarbons to atmosphere, and can arise at any stage of the life cycle.

(8) ***Nutrification (NP)***: Nutrification results from the addition of nutrients to a soil or water system, causing an increase in biomass. Any nutrient can have this effect, but nitrogen and phosphorus are the most crucial species.

(9) ***Acidification (AP)***: This impact is caused by deposition of acid gases such as sulphur and nitrogen oxides onto water bodies.

(10) ***Solid waste generation***: Depending on the type of solid waste, the environmental impacts will be different. The LCA differentiated between the following waste types: ***non-hazardous waste (NW)*** arising from mining and other similar activities; ***hazardous waste (HW)*** comprising bottom ash, fly ash and filter sludge, and ***radioactive waste (RW)*** comprising the waste produced by the proportion of the national electricity system generated by nuclear power (6%).

Each impact category was scored for each of the waste management options. The individual scores were weighted by the "Distance to Target" method relative to the impact created by GWP, and then totalled to obtain a composite score.

<u>The results of the LCA are presented in *Table 4* and in *Figure 1*</u>. In *Table 4*, the environmental burden scores associated with burning waste in the incinerator system (adding the burdens associated with burning fossil fuel in the cement kiln) and the scores associated with burning waste in cement kilns (adding the burdens associated with generating additional heat and electricity) have been summed to provide an overall sub-score for resource depletion and releases to air and water, and an overall sub-score for waste production. These scores are then added to provide a total score for each waste management option, the assumption having been made that the impact categories are all of equal importance.

Table 4 LCA scores for waste management options

Waste	Incinerators			Cement Kiln			Net Benefit to Cement Kiln
	Resources/ Air/Water	*Solid Waste*	*Total Score*	*Resources/ Air/Water*	*Solid Waste*	*Total Score*	
Spent solvent	154	24	**178**	116	44	**160**	**-18**
Filter cake	44	500	**544**	43	11	**54**	**-490**
Paint residues	91	362	**453**	71	26	**97**	**-356**
Sewage sludge	59	80	**139**	53	20	**73**	**-66**

The higher the score the greater the potential environmental impact of a particular waste management option. Therefore a ***net environmental benefit relative to the cement kiln operation is represented by a negative net score***, while a net environmental disbenefit will be represented by a positive net score. **The table shows that regardless of the type of waste, there is a net benefit to the cement kiln option, in terms of all the impact categories considered** (i.e. resource conservation, releases to air, releases to water and the production of solid waste). The impact category of solid waste is perhaps the most significant net benefit accrued to the cement kiln disposal option. Whereas in the case of combustion in dedicated incinerators solid waste disposal fly ash, filter sludge, etc. is a major consideration within the overall life cycle, and involves landfilling and its associated impacts of leachate generation and health effects, the cement kiln option does not generate liquid or solid waste. The small score assigned to solid waste impacts relates to the waste associated with the generation of the additional electricity and heat needed to replace the power produced by the incinerator.

TNO has also developed a "standardised environmental profile" for each disposal option. In this method of presentation, scores for the base case environmental burdens are calculated when one tonne of waste is combusted in an incinerator, and when one tonne of waste is combusted in a cement kiln. From each base case the scores for the avoided environmental burdens are subtracted. In the case of waste combustion in incinerators, the avoided burdens relate to external electricity and heat production. In the case of combustion in a cement kiln, the avoided burdens relate to the savings in fossil fuel and raw material use at the kiln. **A net decrease in emissions is represented by negative scores for the impact categories**, whereas a net addition to environmental burdens is represented by positive scores. Net scores for individual impact categories are shown in *Figure 1* for each waste type. **The summation of individual scores into a single overall score for each waste management option is presented in *Table 5***.

Table 5 Net scores and environmental profiles for waste management options

Waste	Incinerators			Cement Kiln		
	Resources/ Air/Water	*Solid Waste*	*Total Score*	*Resources/ Air/Water*	*Solid Waste*	*Total Score*
Spent solvent	-5	-20	**-25**	-42	-1	**-26**
Filter cake	7	487	**494**	7	-1	**6**
Paint residues	2	330	**332**	-19	-0.2	**-19.2**
Sewage sludge	-5	60	**55**	-9	-1	**-10**

Referring to *Figure 1* and to *Table 5*, the LCA can be summarised as follows:

(1) ***Spent Solvents:*** *Figure 1a* and *Table 5* indicate that there are higher scores for the dedicated incinerator option in relation to resource depletion and to environmental burdens to air, water. There is a higher score for the solid waste category for the cement kiln option due to the burdens associated with the use of fossil and other fuels in external energy generation. However, the net effect is marginally in favour of the cement kiln option.

(2) ***Filter Cake:*** *Figure 1b* indicates higher individual scores for impacts of human toxicity and acidification potential for the cement kiln option, associated with greater emissions of sulphur dioxide and nitrogen dioxide. However, these are counterbalanced by higher scores for other impact categories for the incinerator option, such that the net effect for resource depletion and releases to air and water is neutral. However, there is a large net benefit associated with the solid waste impacts associated with the cement kiln option, which leads to a substantial overall improvement in environmental performance when waste is transferred from an incinerator to a cement kiln.

(3) ***Paint Residues:*** The cement kiln option outperforms the dedicated incinerator options in all impact categories, save for solid waste impacts associated with external generation of electricity and power. The most significant environmental improvement results from the lack of solid waste associated with incinerator operation.

(4) ***Sewage Sludge***: As with the disposal of filter cake, the cement kiln option scores less well on impact categories associated with the greater discharges of sulphur dioxide and nitrogen oxides, but this is more than offset by the environmental improvements obtained in other impact categories, and particularly with solid waste generation and disposal.

Irrespective of the type of waste, the cement kiln option consistently demonstrated a significant overall improvement in environmental performance and hence a positive effect on the environment.

Figure 1a: Impact of Processing Spent Solvents in Cement Kilns and in Specialised Waste Incinerators

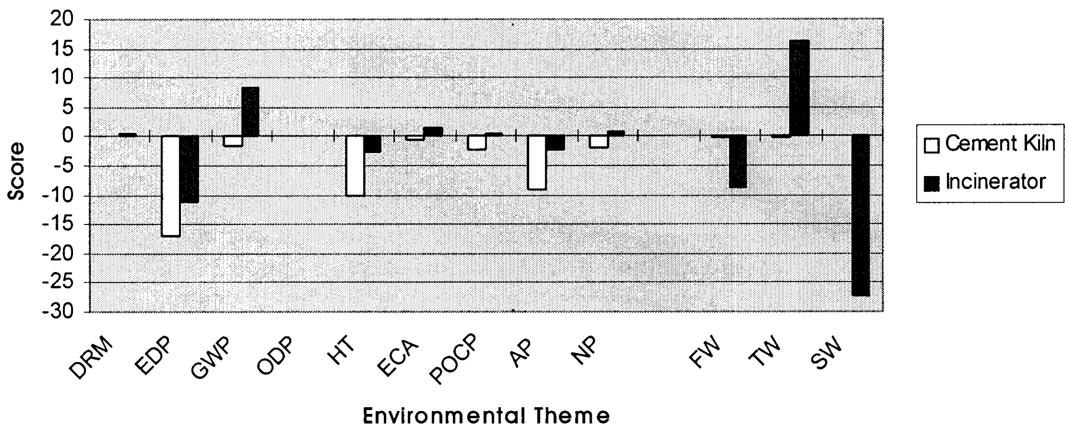


Figure 1b: Impacts of Processing Filter Cake in Cement Kilns and in Specialised Waste Incinerators

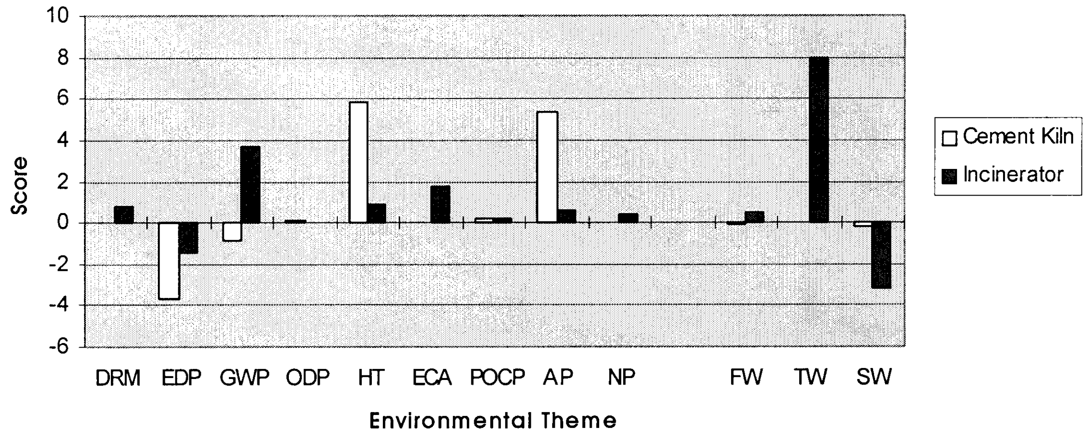


Figure 1c: Impacts of Processing Paint Residue in Cement Kilns and in Specialised Waste Incinerators

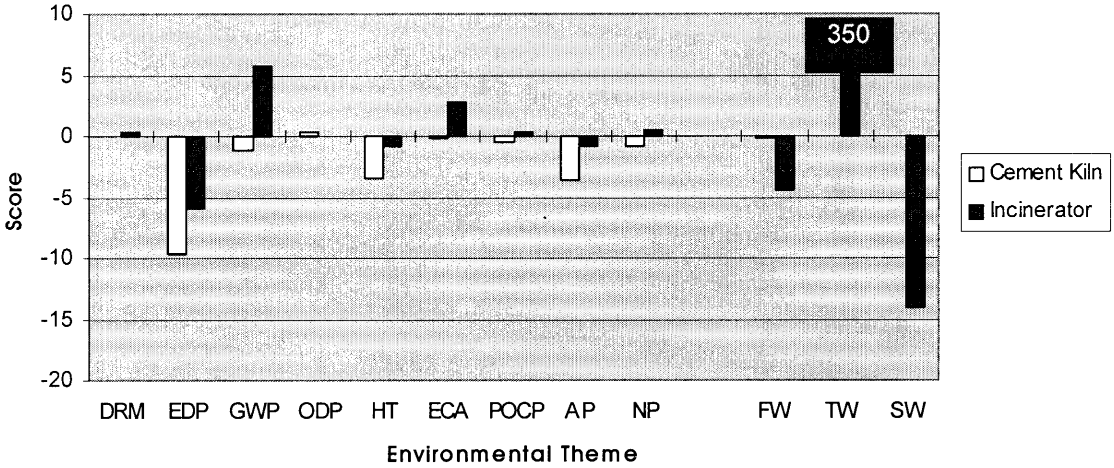
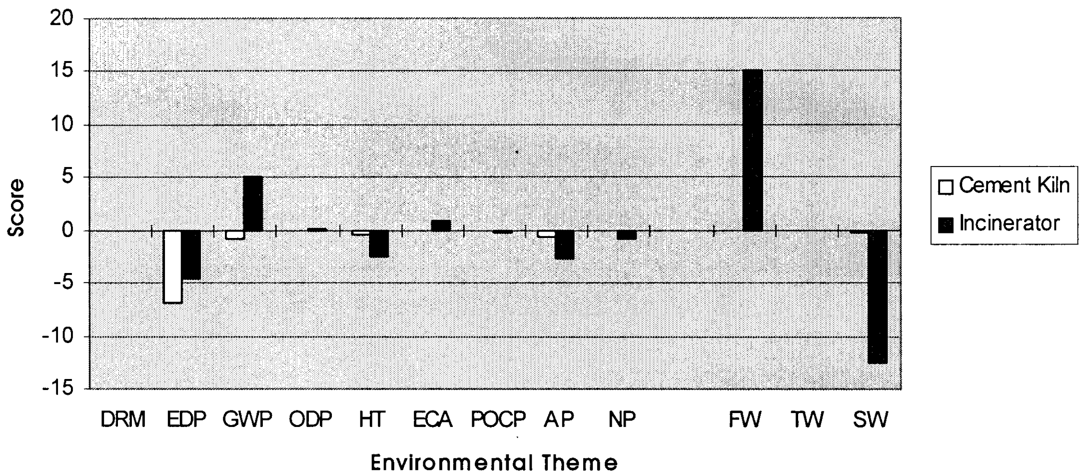


Figure 1d: Impacts of Processing Sewage Sludge in Cement Kilns and in Specialised Waste Incinerators



4. *RECYCLING VERSUS RECOVERY IN CEMENT KILNS*

4.1 INTRODUCTION

As stated in *Section 1*, the European cement industry firmly supports the principle of the waste management hierarchy, and the need firstly to conserve non-renewable resources, and secondly to recover, reuse and recycle materials to their fullest potential. In this regard the **cement industry can play a valuable role in maximising the utilisation of latent energy within a waste material, providing an environmentally beneficial alternative to materials recycling. Two examples illustrate this theme**:

- the recycling of waste plastics versus the utilisation of waste plastic in cement kilns as a heat source;
- the recycling of waste oils versus the utilisation of waste oils in cement kilns as a heat source.

Since each activity (i.e. recycling and use in a cement kiln) has associated upstream and downstream implications in terms of energy use, resource requirements and avoided burdens, LCA is again used to define and analyse the two systems.

4.2 RECYCLING VERSUS UTILISATION OF WASTE PLASTICS

The Fraunhofer Institute[2)] has analysed the environmental performance of the following activities with respect to emissions of CO_2, energy use, and the generation of hazardous waste:

- utilisation of 1 kg of waste plastics in cement kilns, displacing an equivalent amount of fossil fuel in thermal units. This results in avoided emissions relating to the mining, handling, transportation and use of coal at the kiln;
- incineration of 1 kg of waste plastics in an incinerator, along with other municipal solid waste. Fossil fuel is now used in the cement kiln, in the absence of a supplementary fuel;
- recovery by conversion of 1 kg of waste plastic into gaseous and liquid synthesis products using processes such as hydrogenation.

As the base case, it was assumed that 1 kg of waste plastics was landfilled along with other municipal solid waste. This is still the predominant route of disposal for unsorted municipal solid waste within the EU.

The environmental impacts of the waste management options relative to landfilling were assessed for a range of impact categories, including global warming potential, nutrification, acidification potential, solid waste generation, etc. **A selection of environmental burdens are displayed in *Figure 2* and can be summarised as follows:**

(1) ***CO_2 Generation***:
The use of waste plastics in cement kilns as a substitute fuel results in the largest net reduction in CO_2 generation of the three management options, relative to landfilling. For waste incineration, the offset from avoiding external energy generation is insufficient to counterbalance the avoided burden through not having to mine, transport and use coal at the cement kiln. Hydrogenation and conversion of waste to plastic goods itself is an activity that uses energy, resulting in a small net saving in CO_2 generation.

(2) ***Energy Recovery***:
Apart from waste incineration, which is a relatively inefficient converter of latent energy, the other management options offer comparable benefits in energy utilisation relative to landfill.

(3) ***Hazardous Waste Production:***
The cement kiln, hydrogenation and conversion options do not produce hazardous waste, since any waste products are recyclable. However, waste incineration will produce 0.03 kg of hazardous waste per kg of plastics, in the form of fly ash and bottom ash. This waste will require disposal, generally by landfilling.

Overall, the cement kiln option outperforms the remaining options, maximising the beneficial use of waste plastics relative to conventional incineration or conversion into chemical goods.
lubricating oil products would

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2) • *Life Cycle Analysis of Recycling and Recovery of Households Plastics Waste Packaging. Fraunhofer Institute, Munich, 1996*
• *Verwertung von Kunststoffabfällen aus Verkaufsverpackungen in der Zementindustrie. Fraunhofer Institute, Munich, 1997*

Figure 2a: Change in the Potential Environmental Impact in kg CO_2/kg Plastics

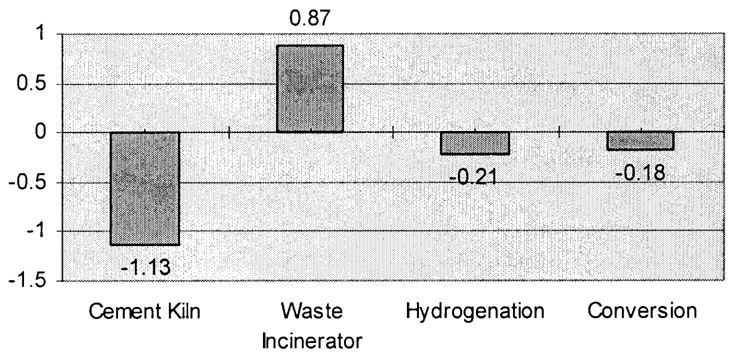


Figure 2b: Saving as a Result of Utilisation of the Energy Content Recoverable from Resources in MJ/kg Plastics

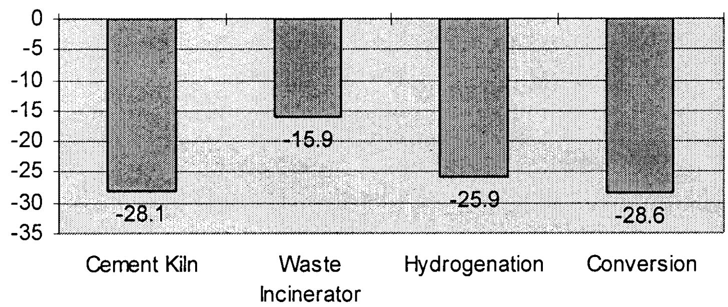
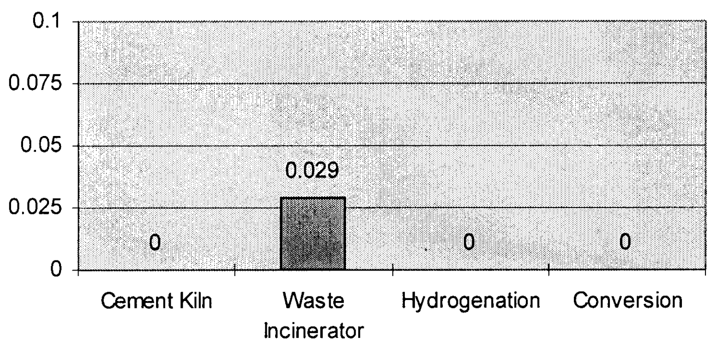


Figure 2c: Change in the Amount of Hazardous Waste Produced in kg/kg Plastics



4.3 Recycling Versus Utilisation of Waste Oils

Another example of the overall benefits that cement kilns can bring to the environment is that of the management of waste oils. Two routes were assessed by the Fraunhofer Institute using the technique of LCA:

(1) The use of waste oils in cement kilns, displacing a conventional fossil fuel such as coal.

(2) The reprocessing of waste oil into lubricating oil products.

In the case of management route (1), the use of waste oil in cement kilns will necessitate the processing of crude oil into virgin lubricating oil products to replace the products that would have been made from the recycling process. Therefore the environmental burdens associated with crude oil processing were added to the environmental burdens resulting from the use of waste oils in cement kilns. Conversely for management route (2) the reprocessing of waste oils into mean the continuation of fossil fuel procurement and use at the cement kiln. Therefore the environmental burdens associated with coal extraction, processing and use in cement kilns were added to the environmental burdens resulting from reprocessing operations.

The LCA results for CO_2 emissions and energy use are displayed in *Table 6*.

As with the utilisation of waste plastics in cement kilns, the use of waste oils as supplementary fuel outperforms the alternative waste management option of reprocessing. **Emissions of CO_2 and overall energy utilisation are approximately 60% lower for the cement kiln option than when the waste oil is reprocessed into lubricating oil products**. Controlled processing of waste

Table 6 Environmental burdens associated with the management of waste oils

Activity	CO_2 Emitted (kg/t waste oil)	Energy Used (MJ/t waste oil)
Reprocessing of Waste Oil		
• Mining & transport of coal	551	4,300
• Waste oil refining	149	2,115
• Coal in cement plants	4,023	462
• TOTAL	4,732	6,877
Waste Oil in Cement Kilns		
• Crude oil procurement	124	1,434
• Crude oil refining	246	2,676
• Waste oil in cement kilns	2,536	17
• TOTAL	2,905	4,121

5. *SUMMARY OF ENVIRONMENTAL BENEFITS PROVIDED BY CEMENT KILNS*

with energy recovery and material recovery within a cement kiln represents an attractive waste management option. With an excess of 300 cement plants spread throughout the European Union, the industry is particularly well placed to respond to Society's needs in this regard. Waste materials which the industry has utilised as alternative fuels include used tyres, rubber, paper waste, waste oils, sewage sludge, plastics and spent solvent. In all cases these waste materials would either have been landfilled or combusted in dedicated incinerators. Their use in cement kilns replaces fossil fuels:

- maximises the recovery of energy while ensuring their safe disposal;
- produces overall environmental benefits by reducing releases to air, water and land;
- prevents resource depletion of valuable non-renewable fossil fuels;
- obviates the need to build dedicated incineration facilities.

The important contribution that the cement industry can make to a nation's waste management infrastructure has been explicitly recognised by several European governments. The practice of employing alternative fuels in cement plants does not hinder the establishment of a sound waste management industry. This practice can co-exist alongside a vigorous and thriving materials recovery and recycling and incineration industry, without distorting the essential principles of the EU's waste management hierarchy.

To this end the cement industry continues to contribute to the furtherance of sustainable development in Europe.

Annex A

CO_2 EMISSIONS WHEN BURNING WASTE

A1. *INTRODUCTION*

The purpose of this note is to develop scenarios describing the emissions of CO_2 during the combustion of waste material in a cement kiln rather than in a dedicated incinerator. The calculations are intended as ***indicative***, to establish broad order of magnitude of net emissions rather than precise emission estimates.

Two scenarios are constructed. In *Scenario 1* the waste is combusted in a dedicated incinerator, and the power generated is fed into the national electricity grid system. The cement kiln operates with a conventional fossil fuel (coal). The releases of CO_2 from this system comprise the following:

- CO_2 from the mining and transportation of coal used at the cement kiln;
- CO_2 from the combustion of coal at the cement kiln;
- CO_2 from the combustion of waste in the dedicated incinerator.

In addition to the above, there are emissions of CO_2 from the power plant, when the latter is operating at reduced load owing to the addition of electricity into the grid from an external source downstream of the power plant. These emissions do not need to be computed if the objective is to examine the net difference between *Scenario 1* and *Scenario 2*.

In *Scenario 2* the waste is now transferred to the cement kiln, displacing an amount of coal in proportion to its heat content. Since the incinerator is no longer operational, electricity is not produced. In order to maintain the overall supply of electricity to the grid, the power plant has to generate an additional amount of electricity equivalent to that previously generated by the incinerator. In most EU Member States this marginal power is generated via the combustion of coal. The releases of CO_2 from this system comprise the following:

- CO_2 from the mining and transportation of coal used at the power plant;
- CO_2 from the combustion of coal at the power plant;
- CO_2 from the combustion of waste in the cement kiln.

The scenarios are described below.

A2. *ASSUMPTIONS*

A summary of the assumptions and their sources is presented in *Table A1*. The assumptions are discussed in more detail below.

Table A1 Summary of Data Input and Other Information

	Heat Content	*CO_2 Emissions*	*Plant Design*	*Reference*
Biofuel	16 GJ/t	110 kg/t	-	(a)
Solvent	26 GJ/t	70 kg/t	-	(b)
Coal	26 GJ/t	93 kg/t	-	(a)
Coal mining	-	24.3 kg/MWh	-	(c)
Coal transportation	-	0.045 kg/km/t	-	(c)
Incinerator efficiency	-	-	23%	(d)
Power plant efficiency	-	-	37%	(c)

Notes:

(a) Nystrom K L E (1993). Incineration waste and the greenhouse effect. ISWA Times, 1993/4 Yearbook. Emission factor for biofuels is the average of emission factors for wood 112 kg/GJ) and domestic waste (108 kg/GJ).

(b) Emission factor estimated on the basis of 55% carbon content, relative to coal with 75% carbon content.

(c) European Commission, DGXII, Science, Research and Development, JOULE (1995a). Externalities of Fuel Cycles 'ExternE' Project.

(d) Wallis M K and Watson A (1994). MSW incineration: a critical assessment. *Energy World*, pp 14-16, December 1994.

A2.1 Fuel and Waste Types

We assume that the conventional fossil fuel used in the cement kiln and in the power plant is coal with a heat content of 26 GJ/t and a CO_2 emission factor of 93 kg CO_2/GJ.

We assume two waste types broadly representative of a biofuel made from waste materials (sewage sludge, refuse derived fuel (RDF), etc.) and a solvent waste derived from chemical wastes. For the biofuel we assume a heat content of 16 GJ/t (typical of RDF) and for the solvent waste we assume a heat content of 26 GJ/t, typical of the specifications for supplementary liquid fuels delivered to cement kilns. The CO_2 emission factor for the biofuel is taken as 110 kg CO_2/GJ, between that of domestic waste (108 kg CO_2/GJ) and a woody waste (112 kg CO_2/GJ). The CO_2 emission factor for the solvent waste is taken as 70 kg CO_2/GJ, assuming a lower carbon content (55%) relative to that of coal (75%).

A2.2 Displacement of Coal

When combusting waste in the cement kiln, the amount of coal displaced will be proportional to the heat content of the waste. Therefore 1 tonne of biofuel will displace 0.62 tonne of coal, and one tonne of solvent waste will displace 1 tonne of coal. Assuming an energy consumption of 4 GJ/t of cement, 1 tonne of biofuel will produce 4 tonnes of cement, while 1 tonne of solvent waste will product 6.5 tonnes of cement.

Under *Scenario 2*, additional coal required in the power plant to supply the energy withdrawn from the electricity grid due to the closure of the dedicated incinerator. Assuming a conversion efficiency at the incinerator of 23%, a conversion efficiency at the power plant of 37%, and a conversion factor of 280 kWh per GJ of heat content, 1 tonne of biofuel will produce 1,030 kWh of electrical energy in the incinerator, equivalent to 0.39 t of coal at the power plant. 1 tonne of solvent waste will produce 1,674 kWh of electrical energy in the incinerator, equivalent to 0.63 t of coal at the power plant.

A2.3 Mining and Transportation of Coal

CO_2 is released during the mining and transportation of coal. The emission factors used are 24.3 kg CO_2/MWh electric from coal mining, and 0.045 kg CO_2/km/t for transportation by rail. It is assumed that coal transportation from the mine to the cement kiln or to the power plant involves a round trip of 300 km.

A3. *SCENARIO 1 - BURNING WASTE IN INCINERATORS*

A3.1 Construction of Scenario 1

For *Scenario 1*, we assume the following:

- 1 tonne of waste is combusted in a dedicated incinerator.
- The cement kiln uses coal as the conventional fuel.
- Electricity from the incinerator offsets an equivalent amount of electricity produced at the power plant, enabling the power plant to operate at reduced load.

Two situations are defined:

- *Scenario 1(a)*: Burning of biofuel in dedicated incinerator.
- *Scenario 1(b)*: Burning of solvent waste in a dedicated incinerator.

The CO_2 **burden** to atmosphere comprises the following:

- (A) CO_2 generated during the mining and transportation of coal.
- (B) CO_2 generated during burning of coal in the cement kiln.
- (C) CO_2 generated during burning waste in the incinerator.
- (D) CO_2 generated at the power plant when the incinerator is on-line.

The total CO_2 burden is therefore:

A + B + C + D

It is not necessary to compute the CO_2 burden defined by (D).

A3.2 CO_2 GENERATED DURING MINING AND TRANSPORTATION OF COAL (A)

With an emission factor of 24.3 kg CO_2/MWh electric from coal mining, 0.045 kg CO_2/km/t for transportation by rail and a round trip of 300 km for transportation to the kiln, the CO_2 burdens are as follows:

- *Scenario 1(a)*: CO_2 emissions from mining of 0.62 t coal is **110 kg** and transportation of 0.62 tonne of coal is **9 kg**. Total is **119 kg**.
- *Scenario 1(b)*: CO_2 emissions from mining of 1 t coal is **177 kg** and transportation of 1 tonne of coal is **13.7 kg**. Total is **191 kg**.

A3.3 CO_2 GENERATED DURING BURNING OF COAL IN THE CEMENT KILN (B)

With an emission factor of 93 kg CO_2/GJ, the CO_2 burdens are as follows:

- *Scenario 1(a)*: CO_2 emissions from combustion of 0.62 t coal is **1,500 kg**.
- *Scenario 1(b)*: CO_2 emissions from combustion of 1 t of coal is **2,418 kg**.

A3.4 CO_2 GENERATED DURING BURNING OF WASTE IN THE INCINERATOR (C)

With an emission factor of **110 kg CO_2/GJ** for biofuel, and **70 kg CO_2/GJ** for the solvent waste, the CO_2 burdens are as follows:

- *Scenario 1(a)*: CO_2 emissions from combustion of 1 t biofuel is **1,760 kg**.
- *Scenario 1(b)*: CO_2 emissions from combustion of 1 t solvent waste is **1,820 kg**.

A3.5 TOTAL CO_2 BURDEN

The total CO_2 burden from Scenario 1 is (A + B + C + D) kg.

- *Scenario 1(a)* = 119 + 1,500 + 1,760 + D = **(3,379 + D) kg**
- *Scenario 1(b)* = 191 + 2,418 + 1,820 + D = **(4,429 + D) kg**

A4. *SCENARIO 2 - BURNING WASTE IN CEMENT KILNS*

A4.1 Construction of Scenario 2

For *Scenario 2*, we assume the following:

- Waste is combusted in the cement kiln, displacing a (thermal) equivalent of coal.
- The incinerator does not function. An equivalent amount of energy is produced in the power plant by mining, transportation and combustion of coal.

Two situations are defined:

- *Scenario 2(a)*: Burning of biofuel in the cement kiln
- *Scenario 2(b)*: Burning of solvent waste in the cement kiln

The CO_2 **burden** to atmosphere comprises the following:

- (D) CO_2 released when the power plant is operating as in *Scenario 1*.
- (E) CO_2 generated during burning of additional coal in power plant.
- (F) CO_2 generated during mining and transportation of additional coal.
- (G) CO_2 generated during burning of waste in the cement kiln.

The total CO_2 burden for *Scenario 2* is therefore:

D + E + F + G

A4.2 Additional CO_2 at the power plant (E)

- *Scenario 2(a)*: 1 t of biofuel will generate **1,030 kWh** electrical energy, equal to **0.39 t coal** at the power plant, giving an additional CO_2 burden of **943 kg** at the power plant.
- *Scenario 2(b)*: 1 t of solvent waste will generate **1,674 kWh** electrical energy, equal to **0.63 t coal** at the power plant, giving an additional CO_2 burden of **1,523 kg** at the power plant.

A4.3 Additional CO_2 emissions from coal use at power plant (F)

- For *Scenario 2(a)*, 1 t of biofuel is equivalent to 0.39 t coal. CO_2 emissions from mining is **69 kg** and from transportation is **5.3 kg**. Total CO_2 emissions is **75 kg**.
- For *Scenario 2(b)*, 1 t of solvent waste is equivalent to 0.63 t coal. CO_2 emissions from mining is **110 kg** and from transportation is **9 kg**. Total CO_2 emissions is **119 kg**.

A4.4 CO_2 emissions from burning waste in the cement kiln (G)

These emissions are identical to CO_2 generated during the combustion of the waste in the dedicated incinerator.

- *Scenario 2(a)*: CO_2 burden due to combustion of 1 tonne of biofuel in the cement kiln is **1,760 kg**.
- *Scenario 2(b)*: CO_2 burden due to combustion of 1 tonne of solvent waste in the cement kiln is **1,820 kg**.

A4.5 Total CO_2 Burden

The total CO_2 burden from *Scenario 2* is (D + E + F + G) kg.

- *Scenario 2(a)* = D + 943 + 75 + 1,760 = **(2,778 + D) kg**
- *Scenario 2(b)* = D + 1,523 + 119 + 1,820 = **(3,462 + D) kg**

A5. *NET CO_2 BURDEN*

The net CO_2 burden of the two scenarios is obtained by subtracting the total burden of *Scenario 2* from the burden of *Scenario 1*. The benefit (reduction) in CO_2 emissions from burning waste is cement kilns as opposed to dedicated incinerators is summarised in *Table A2*.

Table A5 *Summary of CO_2 emissions from burning 1 tonne of waste in a dedicated incinerator or in a cement kiln*

	Biofuel (16 GJ/t)	*Solvent Waste (26 GJ/t)*
Incineration in dedicated incinerator	3,379 + D kg CO_2	4,429 + D kg CO_2
Combustion in cement kiln	2,778 + D kg CO_2	3,462 + D kg CO_2
Net benefit due to combustion in cement kiln	**601 kg CO_2/t waste**	**967 kg CO_2/t waste**

A6. *BENEFITS OF BURNING WASTE IN CEMENT KILNS*

Therefore, burning of waste in a cement kiln results in the following benefits:

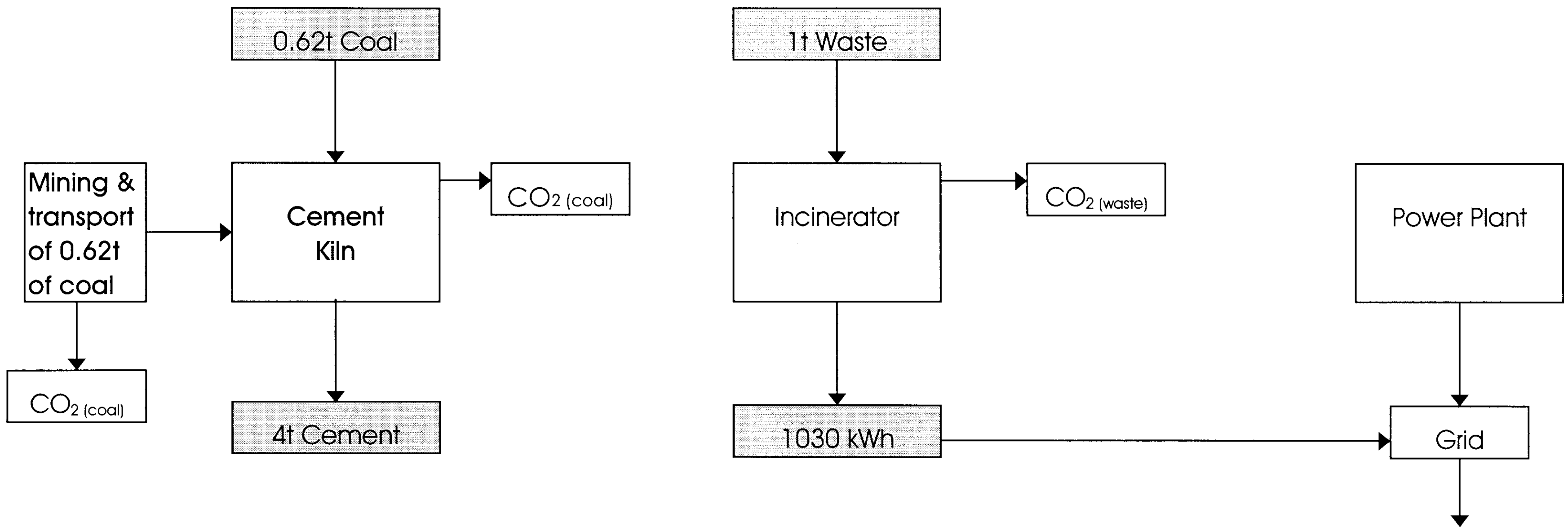
(1) Substitution of coal, a non-renewable resource, with waste, an unwanted material that will require safe treatment and/or disposal. Savings are made through resource conservation and associated CO_2 emissions.

(2) Making more efficient use of the intrinsic energy of the waste material. Specialist waste incinerators are very inefficient converters of the heat content of wastes, whereas a cement kiln approaches 100% efficiency.

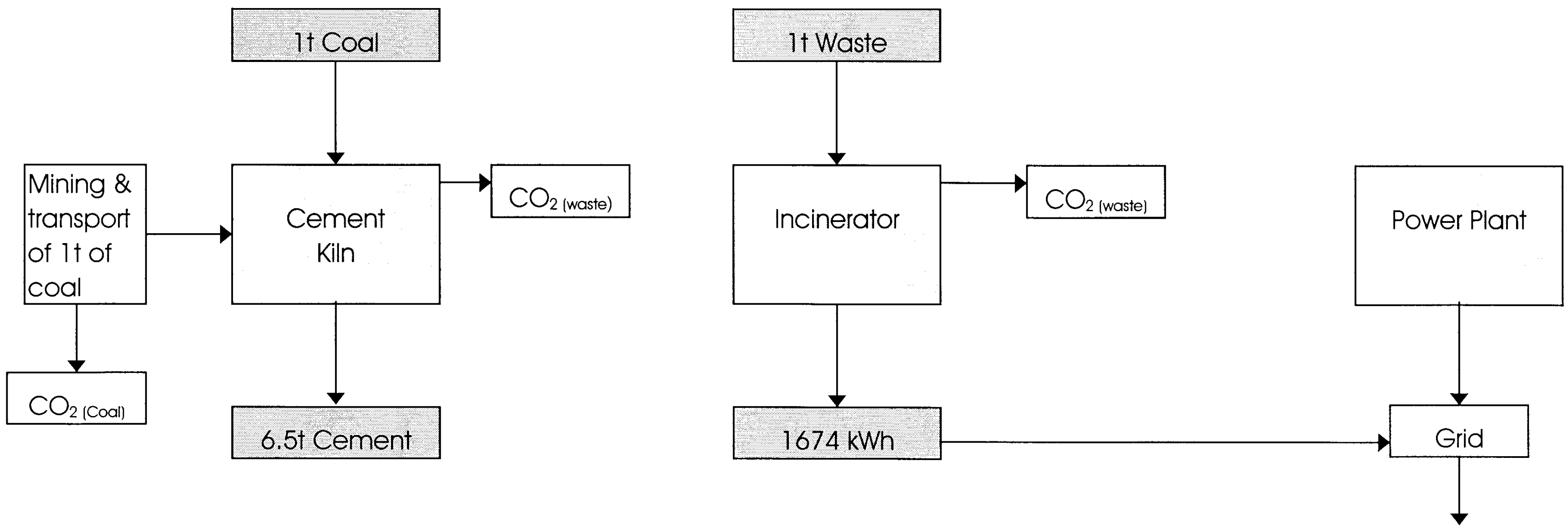
(3) Provision of combustion capacity for incinerable wastes in existing thermal plants which are environmentally safe and secure, obviating the need for dedicated, specialist combustion capacity to be constructed.

(4) A net decrease in the quantity of CO_2 released, relative to a scenario in which waste is combusted in a dedicated incinerator, thereby reducing the environmental impact of the greenhouse effect during the combustion of wastes.

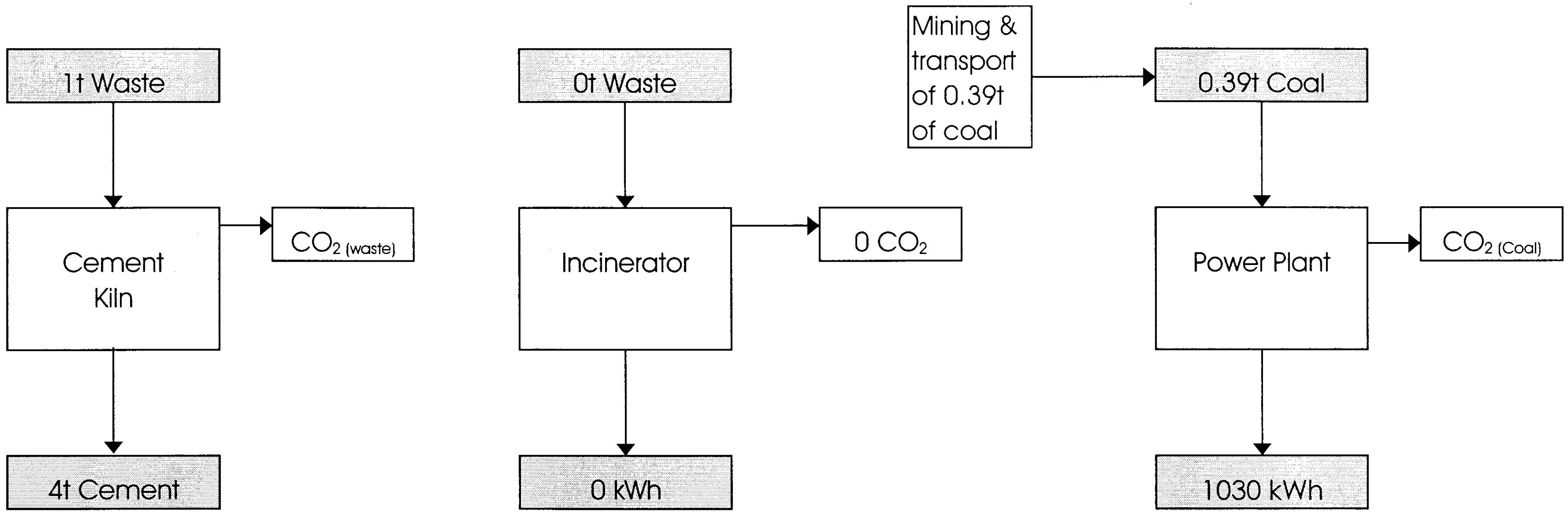
SCENARIO 1 (A) - BIOFUEL WASTE (16GJ/T)



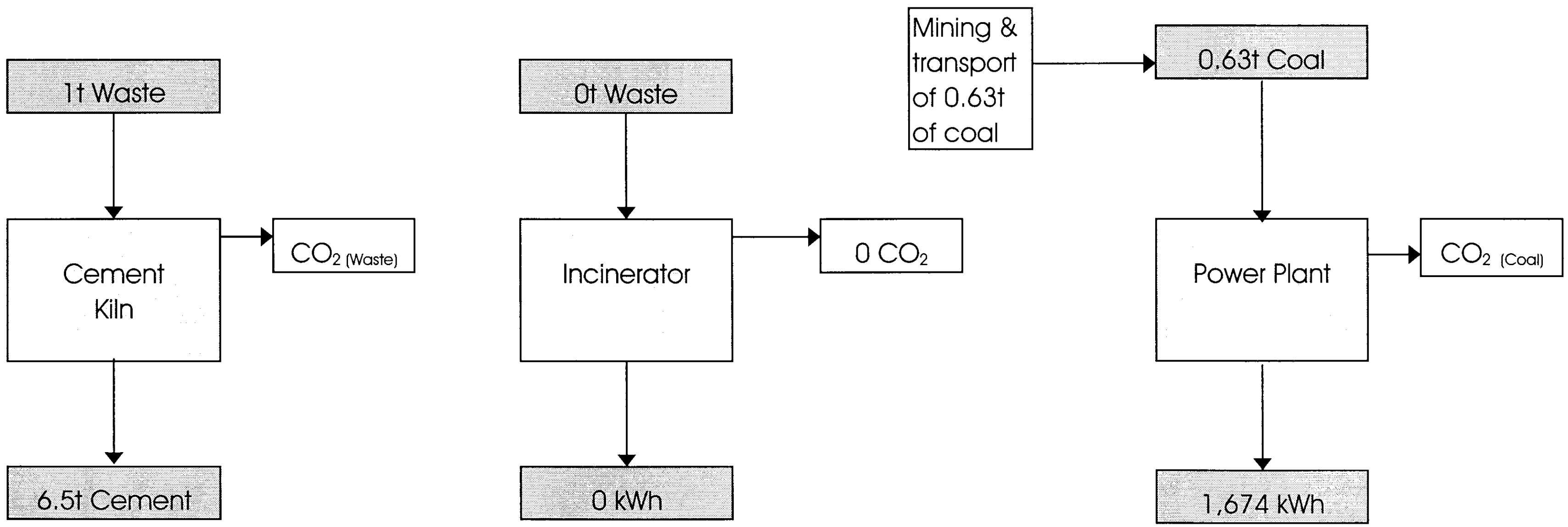
SCENARIO 1 (B) - SOLVENT MIX (26GJ/T)



Scenario 2 (A) - Biofuel Waste (16GJ/t)



Scenario 2 (B) - Solvent Mix (26GJ/t)



N° Editeur: D/1999/5457/February

Published by CEMBUREAU
The European Cement Association

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Layout & Printing by

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