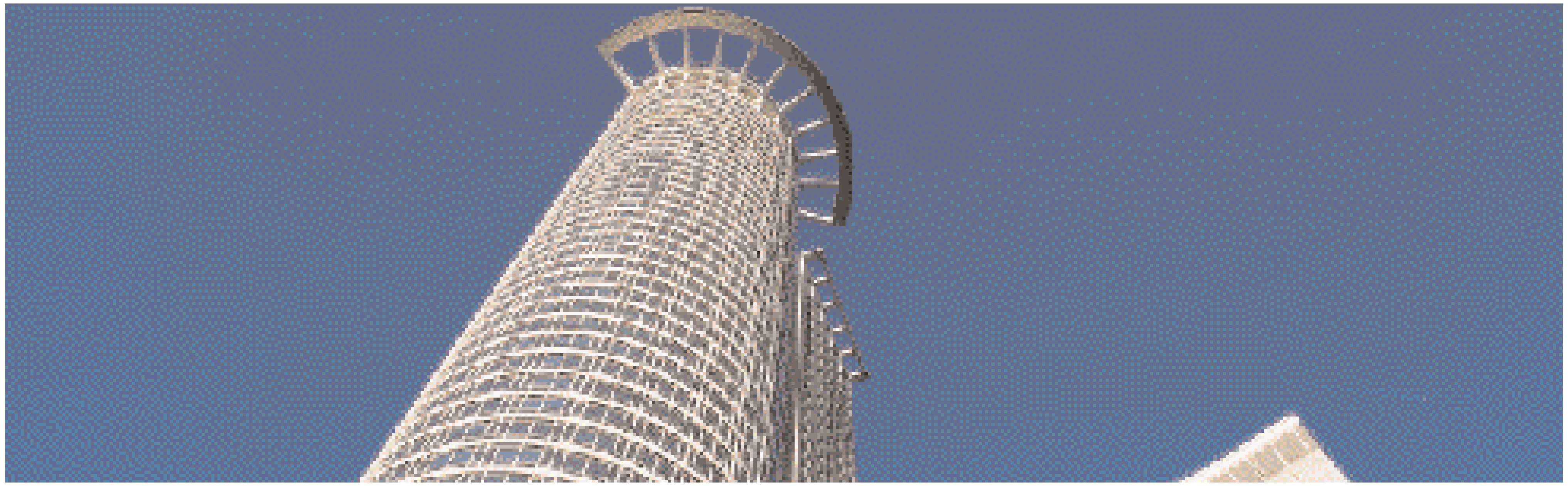
Environmental compatibility of cement and concrete.
Manufacture, application and use of alternative materials.
Information from the German cement industry.

Concrete

Hard
as rock
Strong
on performance
Fair
to the environment

VDZ
Verein Deutscher Zementwerke e.V.
Forschungsinstitut der Zementindustrie

0 Summary



To make an ecological assessment of cement and concrete, all their life phases extending from production and processing, via service life, and as far as disposal must be taken into consideration. Results from comprehensive investigations on the environmental compatibility during all these phases are available. The emissions released in cement manufacture result in ambient pollution concentrations at production sites that amount to less than one per cent of the applicable limit values. The contribution to ambient pollution by organic substances falls significantly below the permissible values. The input of substances, e.g. heavy metals, into the soil in the vicinity of cement plants is of no environmental relevance either.

Elements such as lead, cadmium, and zinc are present in insoluble form in the fresh concrete phase and are therefore not released. Chromium, although readily soluble in the beginning, is fixed in the hydration phases as hydration progresses, i.e. as the concrete gradually hardens. Afterwards it is present in insoluble form.

Trace elements in concrete components are fixed in the paste matrix and thus immobile. Hence, there is little release of heavy metals from concrete. No adverse effects caused by the liberation of gases from concrete are detected during service life. The radioactivity of concrete is of marginal importance as well. The average radon exhalation of concrete falls short of that of the natural soil by two orders of magnitude.

Nowadays many of the initial materials required in cement manufacture are substituted for by suitable alternative materials. This affords several advantages: The use of alternative materials in cement manufacture allows the improvement of the economic efficiency of the production process, simultaneously enabling cement plants to contribute to environmentally compatible utilization. From an overall ecological point of view, the recovery of alternative materials in cement plants outperforms other methods of recovery or disposal.

The investigations carried out show that the concentrations of heavy metals in the rotary kiln exhaust gas are not environmentally relevant if alternative materials are utilized. The dioxin and furan contents fall significantly below the limit value of 0.1 ng TE / m^3, regardless of whether standard fuels or alternative fuels are used. All the organic compounds contained in the fuel are destroyed in the rotary kiln. The utilization of alternative materials in the clinker burning process permits complete material and energy recovery without any product-specific residuals being produced. All the investigations have substantiated that the environment is not polluted by heavy metals being released from concrete components.

Even if cement is made from alternative materials, the concrete produced from it is fully recyclable.

As a consequence, the use of alternative materials in cement manufacture neither impairs the environmental compatibility of the cement production process, nor that of cement and concrete as products. Thus, concrete is an ecological building material that is environmentally compatible both in production and in use and can be fully recycled.

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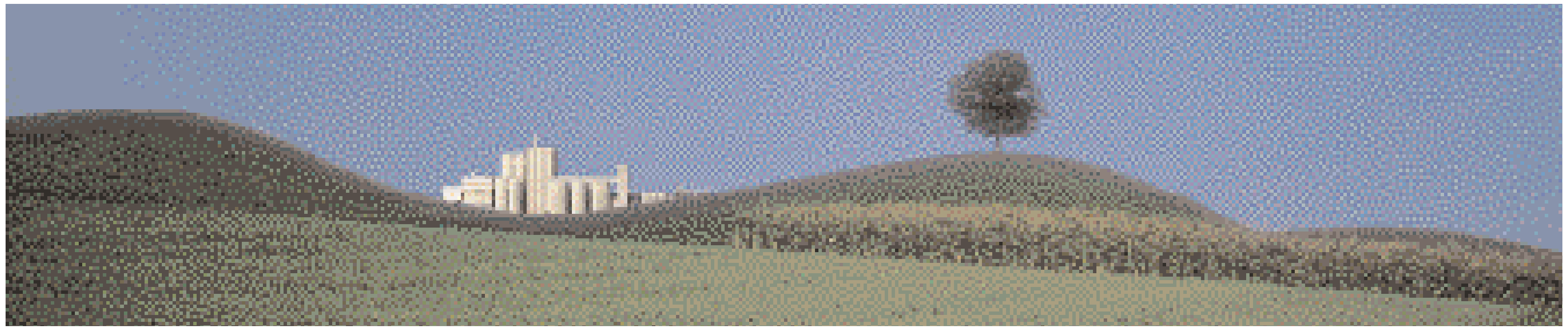

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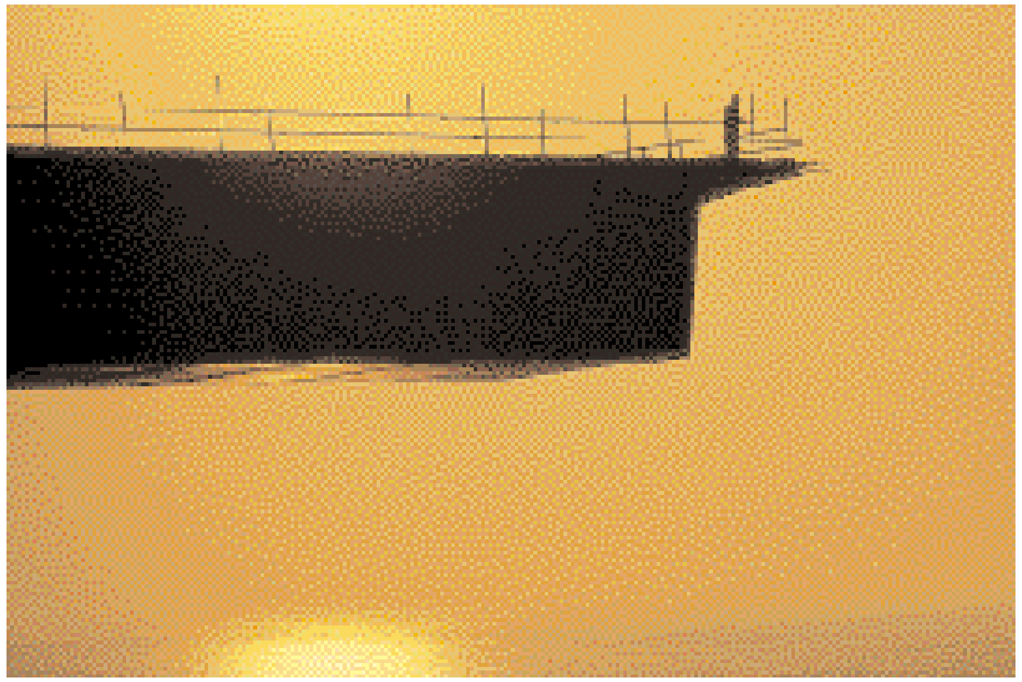


1 Manufacture and application of cement

1.1 Properties and initial materials

Last year, 41 companies with their 70 plants produced about 31 million tonnes of cement in Germany. The cement plants are located in the immediate vicinity of limestone deposits. Cement is a homogeneous bulk commodity that, given the cost of transport, is almost exclusively delivered to local markets. For that reason, production facilities are spread evenly all over the Federal Republic, as can be seen from Fig. 1.

Cements used in Germany must comply with the requirements and definitions of cement standard DIN 1164. Factory production control and third party inspection therefore serve to ensure cement quality as early as in the production stage.

The product is an hydraulic binder, i.e. an inorganic, finely ground substance that automatically sets with water whether it is exposed to air or submerged in water. Under these conditions it retains its strength permanently.

Cement is produced by intergrinding Portland cement clinker and calcium sulfate (natural gypsum, anhydrite or gypsum from flue gas desulfurization plants). In addition to that, cement can contain other main constituents, such as granulated blastfurnace slag, natural pozzolan (e.g. trass), fly ash, burnt oil shale, or limestone. Fig. 2 schematically illustrates the cement production process.

1 Manufacture and application of cement

1.1 Properties and initial materials

What is known as Portland cement clinker is made from a mix of raw materials primarily consisting of calcium oxide (CaO), silicon dioxide (silica (SiO_2)), aluminium oxide (alumina (Al_2O_3)), and iron oxide (Fe_2O_3).

These chemical constituents are derived from limestone, chalk and clay, or their natural blend, lime marl. Limestone and chalk are composed of calcium carbonate ($CaCO_3$). The main constituents of clay are fine-grained mica-like clay minerals and smaller quantities of quartz and felspar. Clay minerals and felspar are compounds of silicon dioxide with aluminium oxide and the alkali oxides Na_2O and K_2O. Quartz exclusively consists of silicon dioxide. The iron oxide also required for melt formation is present in the clay either as a constituent of the clay minerals or as ferrous hydroxide, or it is added in the form of iron ore.

For the cement to conform to the DIN standard, the raw material composition must be accurately complied with. Only a small margin of deviation can be tolerated.

For that reason, the raw materials are subject to strict quality control. Only if the requirements for the preparation and homogenization of the raw material mix are strict can it be ensured that a defined and constant composition of the starting materials is fed to the kilns. The raw material mix is heated up to a temperature of more than 1400° centigrade in a rotary kiln until it starts sintering. This results in the starting materials forming new compounds known as clinker phases. These are certain calcium silicates and calcium aluminates which confer on the cement its characteristic features of hydraulic setting.

Upon addition of calcium sulfate and, in case of need, other main constituents the clinker burnt in the rotary kiln is subsequently ground to cement in finish mills.

The calcium sulfate serves to adjust the setting behaviour of the cement in order to obtain optimum workability of the product during concrete production. Apart from cement clinker, materials of silicate or aluminate nature or lime-containing substances represent the main constituents. They contribute to the hydraulic setting of cement, or have beneficial effects on the physical properties of concrete.

The twelve cement types presently approved in Germany cover the wide range of cement-bound building materials.

For quality requirements to be met, the properties and dosage of clinker and gypsum as well as of the interground additives used in cement grinding must be such as to ensure a defined and homogeneous composition of the cements produced.

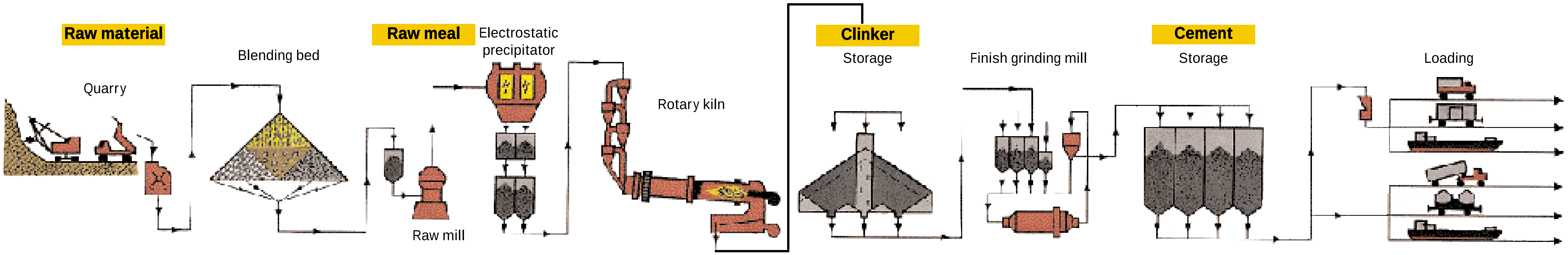


Fig. 2
The cement production process

1.2 Portland cement clinker produktion: The clinker burning process

In Germany most of the Portland cement clinker – or in short cement clinker – is nowadays burned in rotary kilns with so-called cyclone preheaters (preheater kilns) by using the dry process. Part of the clinker is also produced according to what is known as the semi-dry process, which consists of heating the raw material in a grate preheater prior to burning it to clinker in the rotary kiln (Lepol kiln).

Limestone and clay or their natural mix, lime marl, which are the starting materials for cement clinker, are comminuted, dried, and heated to 1450°C. This procedure triggers the chemical reactions that result in the formation of cement clinker. It later confers on the cement its hydraulic properties (setting whether it is exposed to air or submerged in water).

In rotary kiln plants comprising cyclone preheaters the raw material is fed to the preheater as finely ground meal and preheated to about 750°C by the counter-current flow of the kiln exhaust gas.

The limestone contained in the raw meal is hardly calcined by that time. Calcination, i.e. the separation of CO_2, mainly takes place in the calcining zone of the rotary kiln. Cyclone preheater plants comprising precalcining devices are equipped with a so-called calciner. The hot meal discharged from the second cyclone stage from the bottom is swept away by the hot gas flowing upward from the rotary kiln and conveyed to the calciner. In this process, the kiln exhaust gas is suddenly cooled from between about 1000 and 1100°C to the calcination temperature of approximately 850°C. For the endothermic calcination reaction to be maintained, fuels that may – depending on the kiln plant – account for a thermal input of up to 60% of the aggregate fuel energy requirement, are supplied in the calciner (Fig. 3).

With grate preheater plants, the raw material mix, which is dry at the beginning, is formed into pellets by adding water. In the grate preheater, these pellets, which are disposed on a travelling grate, are passed through a tunnel subdivided into a hot chamber and a drying chamber. Not until afterwards do they enter the actual rotary kiln (Fig. 4).

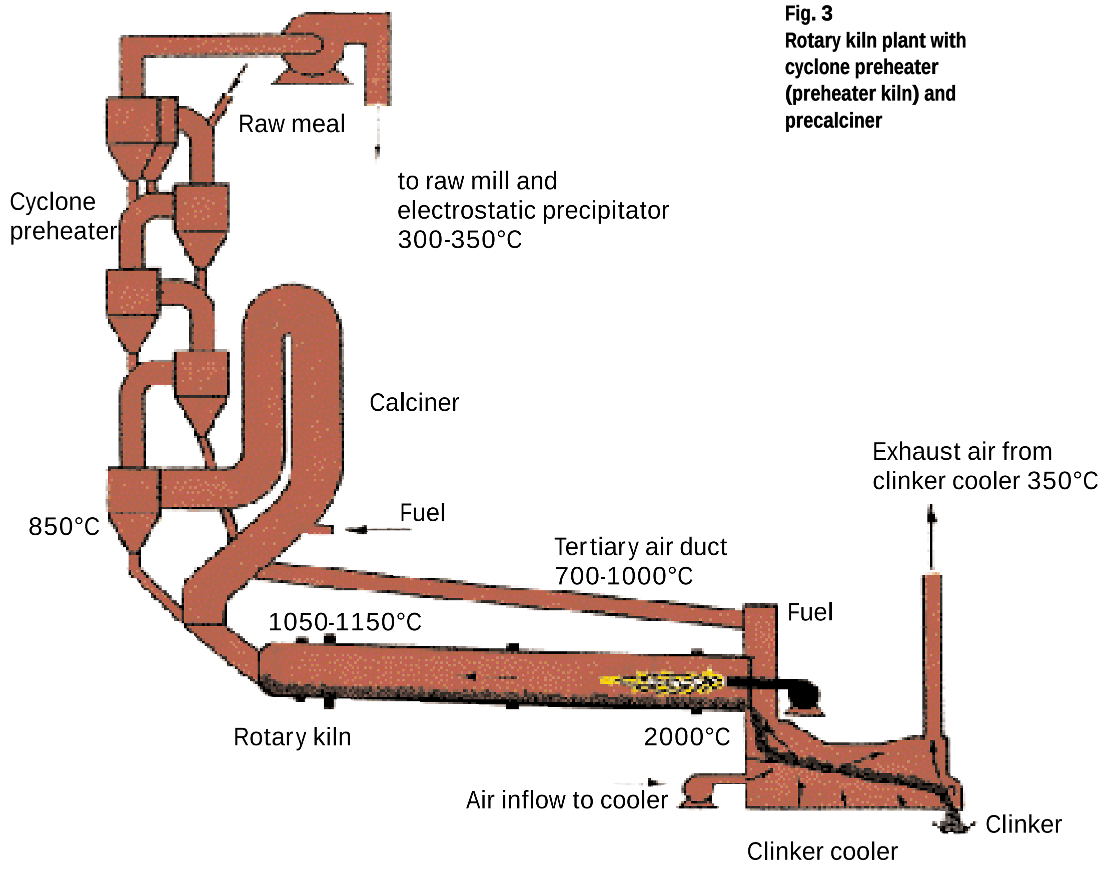


Fig. 3
Rotary kiln plant with cyclone preheater (preheater kiln) and precalciner

1.2 Portland cement clinker produktion: The clinker burning process

The rotary tube of the kiln plant is lined with refractory material. The rotation and the inclination of the kiln axis cause the kiln feed to be conveyed from the kiln inlet towards the burner, which is installed at the kiln outlet. In the so-called sintering zone the kiln feed reaches temperatures of up to 1450°C. The passage time of the material through the kiln ranges between 20 and 30 minutes.

From the rotary tube, the clinker is conveyed to the clinker cooler, where it is cooled by air injection. The thermal energy is recuperated in this process, heating up the secondary air (combustion air). In rotary kiln plants with precalcination and tertiary air duct, part of the heated cooling air is conducted past the rotary kiln to the calciner (tertiary air). It serves as combustion air for the fuels supplied in the calciner.

Since energy is reclaimed in the clinker cooler, and the heat of the kiln exhaust gas is moreover used for drying and heating up the raw material, the clinker burning process boasts a high degree of efficiency of 80 to 90%.

Fuel energy is utilized for burning the cement clinker in cement manufacture. The high temperatures prevailing in the rotary kiln are indispensable for the formation of the clinker mineral phases that are crucial for the cement properties.

The predominant energy sources used in the clinker process in Germany are coal and lignite. Fig. 5 gives a complete summary of the fuel quantities consumed by the German cement industry in 1994. In comparison with 1994, about 10 to 13 per cent of the aggregate fuel energy requirement of the German cement industry is currently being met by the use of alternative fuels.

All the ashes resulting from fuel combustion form necessary mineral constituents of the clinker which are taken into account when the composition of the raw material constituents is chosen. A corresponding proportion of raw material can thus be conserved. For that reason, fuels rich in inerts, i.e. having a high content of ash, are particularly suitable for use in the clinker burning process. In addition to that, they do not generate any residues.

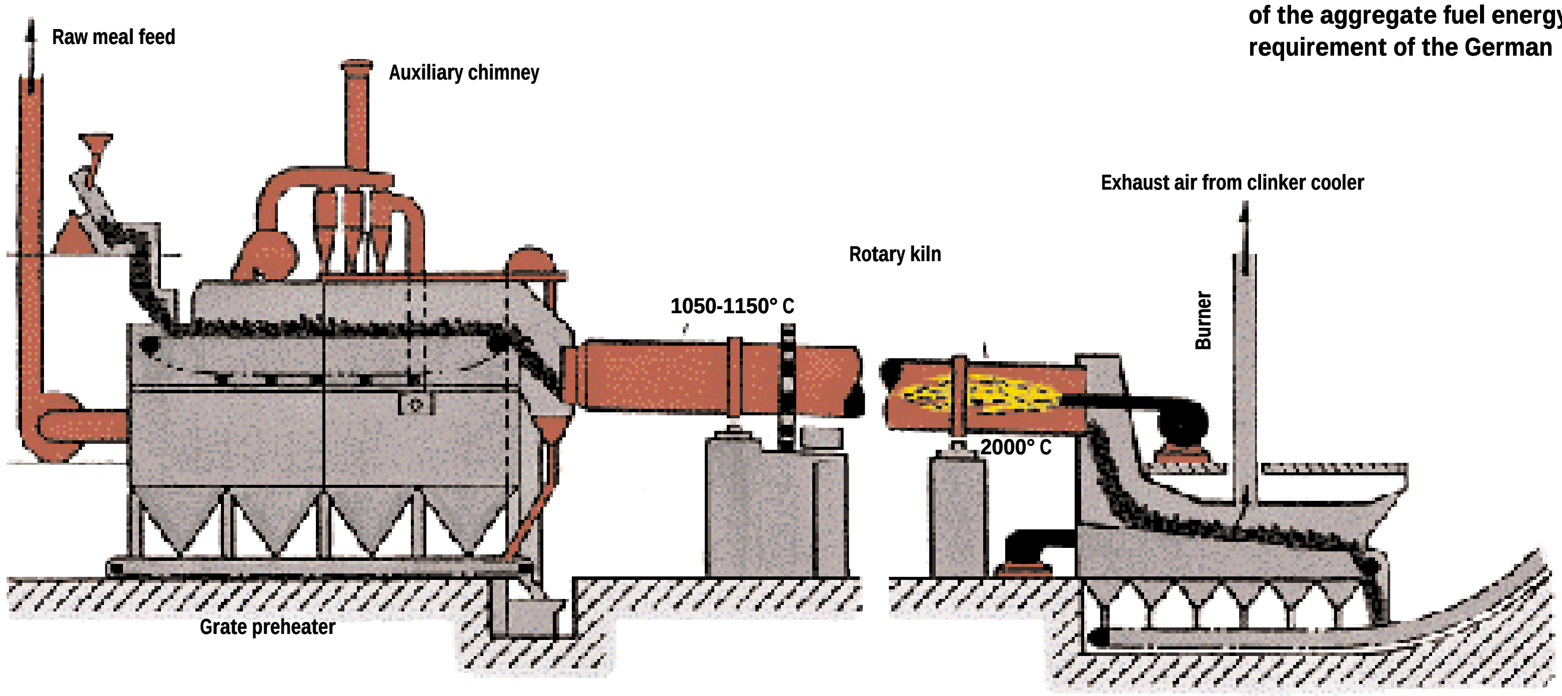


Fig. 4
Rotary kiln plant with grate preheater (Lepol kiln)

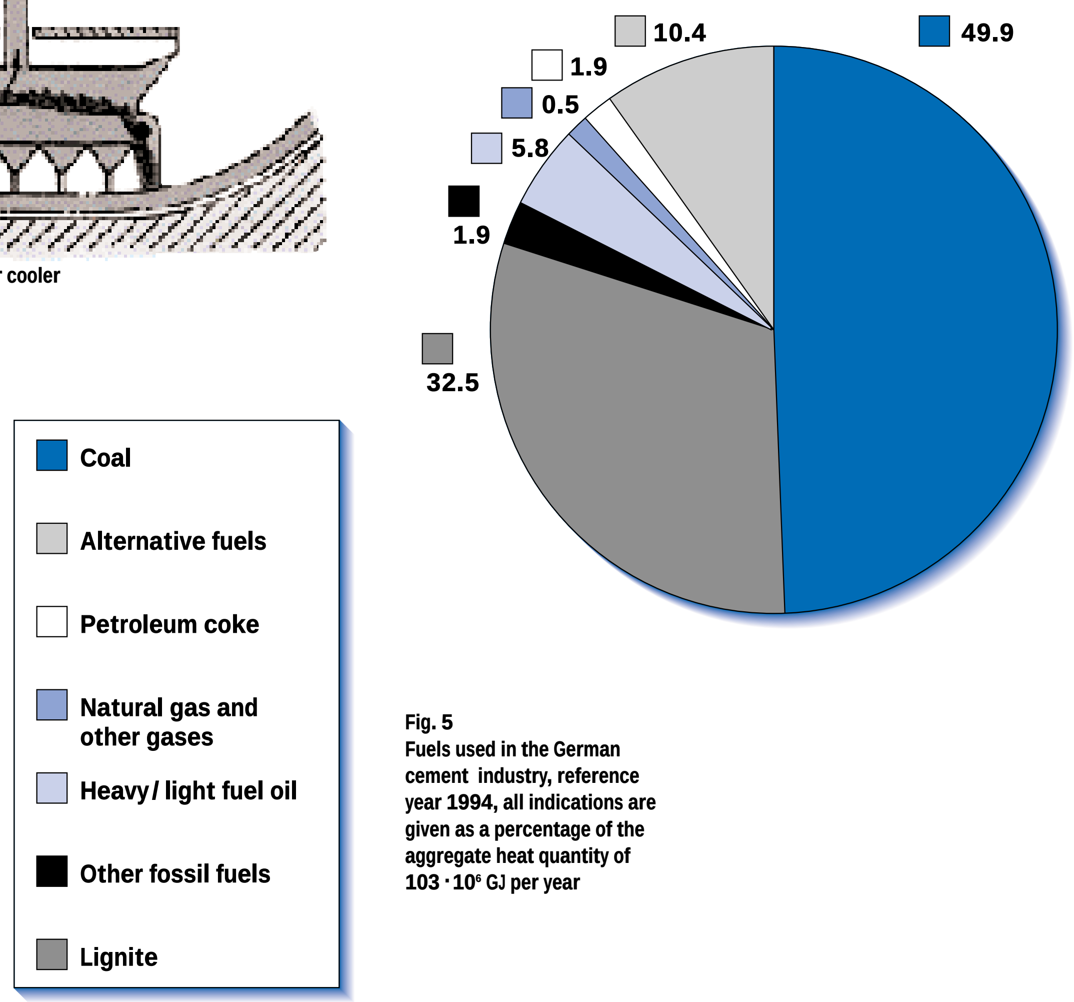


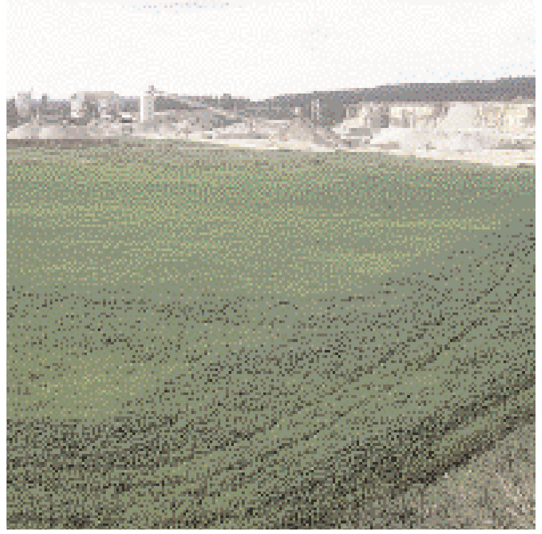
Fig. 5
Fuels used in the German cement industry, reference year 1994, all indications are given as a percentage of the aggregate heat quantity of 103 · 10⁶ GJ per year

2 Environmental compatibility of cement

2.1 Cement manufacture

For the ecological assessment of cement, all its life phases have to be taken into consideration. This includes both the manufacture of cement and its use in concrete (Fig. 6). Ambient pollution levels in the vicinity of production facilities are an environmentally relevant aspect of cement manufacture. Throughout the service life of the component it must be investigated whether any environmentally relevant constituents are released from concrete components. If so, their quantity and the time period of their release are to be determined. Ecobalances summarize all the environmentally relevant input and output factors throughout the life cycle of a component. Only the evaluation and the comparison of such inventories make it possible to compare different building materials with regard to the extent of their environmental impact.

The environmental compatibility of the cement production process can be measured using ambient pollution levels in the vicinity of production facilities. Cement plants are no longer the main source of ambient pollution in the vicinity of works these days. For example, there is just as little dust deposition in rural areas where cement is produced as in purely rural areas without that kind of industry. It becomes apparent from the figures listed in Table 1 that the same applies to the contribution to ambient pollution levels by other air-borne pollutants. The additional impact caused by individual ambient pollution components ranges within one per cent of recognized action thresholds at the most and usually lies significantly below this value.



The contribution of organic substances to ambient pollution levels even falls short of the permissible values by several orders of magnitude.

Based on the example of heavy metals, Table 2 illustrates the maximum calculated input into the soil in the vicinity of a cement works resulting from the emissions of the rotary kiln plant. The input figures are compared with guide values for unrestricted use. As can be gathered from the table, the values of the heavy metals listed lie significantly below the respective soil guide values. If the calculations were not based on the emission limit values, but on actual emission concentrations instead, input into the soil would be even less.

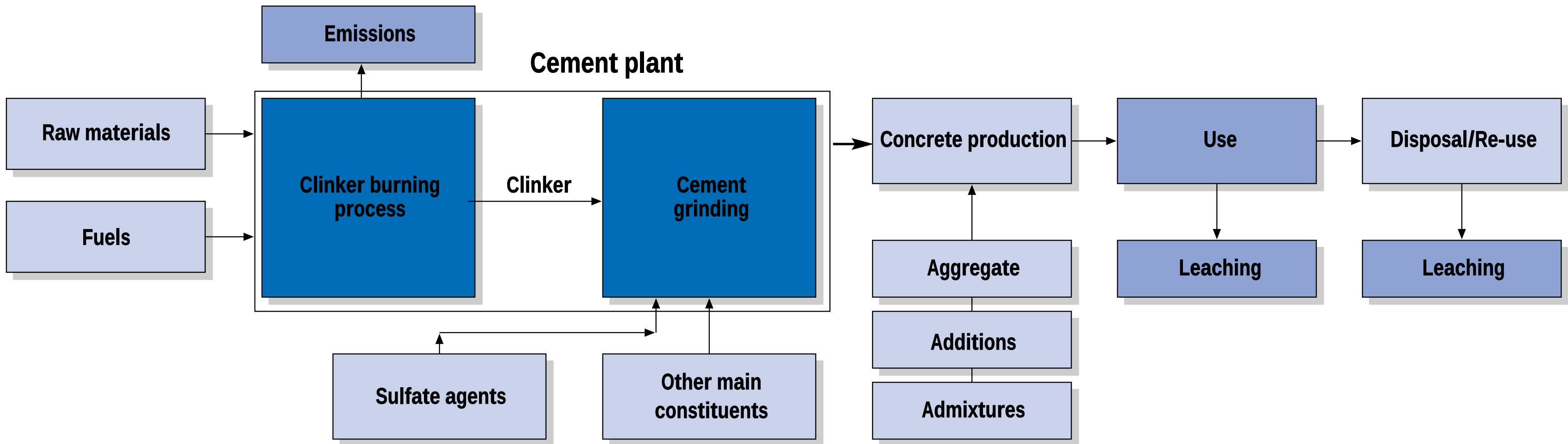


Fig. 6
Life cycle of cement and concrete

2 Environmental compatibility of cement

2.2 Heavy metal behaviour in concrete

Fresh concrete phase

In concrete production, cement, aggregates, and – if necessary – additions and admixtures are mixed with water. The fresh concrete ready for use has a pH value of 12.5 to 13.5 owing to the alkalis of the cement. This high natural alkalinity may cause eye irritation upon direct contact, as well as skin irritation following fairly long contact. For that reason, appropriate gloves and protective clothing should be worn if fresh concrete is handled manually.

Investigations carried out by the Research Institute of the Cement Industry have revealed that for example the elements lead, cadmium, and zinc are present in insoluble form and can therefore not be released. Tests in which these heavy metals were deliberately added to the mixing water have shown that, in the presence of cement, they are integrated into insoluble compounds and fixed in the hardened cement paste matrix. Less than one per cent of the quantity of thallium input is present in soluble form. Only chromium is highly soluble initially. As hydration progresses, i.e. as the concrete hardens, the dissolved chromate inevitably generated in cement manufacture is, however, fixed in the hydration phases. In the hardened concrete or mortar it is insoluble and completely harmless.

The content of water-soluble chromate can trigger a sensitization of the skin in case of frequent contact. Depending on a person's physical constitution and on the duration and intensity of exposure, an allergy to chromate may be the consequence (cement eczema). Owing to largely automated and machine-controlled production, however, this is a minor hazard nowadays.

Frequent and intensive skin contact can, however, not always be avoided when handling bagged cement. Due to the allergeneous effects of the chromate and the alkalinity of the mixed cement improper handling without taking protective measures can cause skin problems. For that reason, German cement manufacturers have started to additionally offer low-chromate standard cement in bags. This cement is marked by the imprint "Low-chromate according to TRGS 613" and conforms to DIN 1164 quality.
As fresh concrete and mortar continue to be alkaline, however, persons handling it must wear suitable protective gloves and take precautionary skin care measures all the same. This combination of measures is the only way of effectively combating allergies to chromate.

Table 1

Environmental relevance of the ambient pollution caused by relevant airborne pollutants (emission concentration corresponds to limit value)

Pollutant	Contribution to ambient pollution in % of recognized action thresholds
Suspended dust*)	0.3
Mercury	0.04
Cadmium	0.05 - 1
Thallium	0.002
Lead	~ 1
Sulfur dioxide	0.5 - 1
Nitrogen dioxide	1.1
Dioxins/Furans	0.3
2, 3, 7, 8 TCDD	< 0.001
Dust deposition*)	~ 1
Components in the dust deposition	0.001 - 0.8

*) without fugitive sources

Table 2

Environmental relevance of heavy metals emitted by a rotary kiln system in a cement works at maximum permissible concentrations (limit value) (total accumulation over 30 years)

Component	Guide values*)	Forecast 30 years	Portion
	mg/kg	µg/kg	%
Arsenic	20	11	0.06
Lead	100	182	0.18
Cadmium	1	4	0.40
Chromium	50	56	0.11
Cobalt	30	11	0.04
Copper	50	34	0.07
Nickel	40	56	0.14
Thallium	0.5	0.7	0.15
Mercury	0.5	14	2.7
Zinc	150	20	0.01
Tin	50	11	0.02

*) Guide values for soils subjected to multifunctional use according to Eikmann-Kloke

2.2 Heavy metal behaviour in concrete

Working life

Heavy metals are present in varying concentrations in all the initial materials for the production of cement and concrete. The respective contents and the input quantities determine the trace element content in the finished concrete component.

All the initial materials contain primary, secondary, and trace elements. Between them, primary and secondary constituents account for more than 99% by mass. The concentration of heavy metals present in traces is usually < 100 ppm, or 0.1 kg / t.

By way of example, the Table below summarizes band widths of heavy metal contents of lead, cadmium, chromium, nickel, thallium, mercury, and zinc for the raw materials limestone, lime marl, and clay / argillaceous rock. It becomes apparent that the heavy metal contents of the raw materials are low and grow higher from limestone via lime marl to clay / argillaceous rock. The subsequent table features the maximum trace element contents in standard fuels, such as coal and lignite, as compiled by the State Environmental Ministry of North Rhine-Westphalia in Essen. Two additional tables summarize the contents found in other possible main constituents of cement and in the calcium sulfates anhydrite and gypsum.

Trace elements are input into concrete via aggregates, cement, and additions. The quantity input via admixtures is negligible. The same applies to the input via mixing water. Gravel and sand are the principal aggregates used; depending on their local availability, limestone and basalt chippings, among others, may be applied as well. Fly ash from bituminous coal is almost the only concrete addition used. The table below summarizes the maximum heavy metal contents for the aggregates gravel and sand and for the addition fly ash from bituminous coal, and their maximum contents in concrete. The comparison of maxiumum heavy metal contents in concretes shows that these contents are comparable to those in natural rocks (Tables 7 and 8).

Table 3

Band widths of heavy metal contents in limestone, lime marl and clay/argillaceous rock, given in ppm (g / t)

Elements	Limestone	Lime marl	Clay/argillaceous rock
	from-to	from-to	from-to
Lead	0.27 - 21	1.3 - 8.5	9.7 - 40
Cadmium	0.02 - 0.50	0.04 - 0.35	0.05 - 0.21
Chromium	0.70 - 12.3	4.6 - 35	20 - 90
Nickel	1.4 - 12.9	5.9 - 21	11 - 70
Mercury	0.005 - 0.10	0.009 - 0.13	0.02 - 0.15
Thallium	0.06 - 1.8	0.07 - 0.68	0.60 - 0.90
Zinc	1.0 - 57	24 - 55	55 - 110

Table 4

Trace element contents in fuels
(standard fuels: maximum contents according to Winkler)

Constituent	mg/MJ	Constituent	mg/MJ
Beryllium	0.13	Tellurium	0.04
Cadmium	0.3	Antimony	0.07
Mercury	0.06	Lead	10
Thallium	0.15	Chromium	3.7
Arsenic	1.9	Copper	3.7
Cobalt	1.2	Vanadium	6.7
Nickel	3.5	Tin	0.4
Selenium	0.2	Zinc	8

Table 5

Band widths of heavy metal contents in granulated blastfurnace slag, fly ash, trass, and oilshale as the main cement constituents, given in ppm (g / t)

Elements	Granulated blastfurnace slag	Fly ash from bituminous coal	Oilshale	Trass
Lead	1 - 10	58 - 800	10 - 50	10 - 70
Cadmium	0.01 - 0.5	0.2 - 4	0.5 - 3.0	0.1 - 1.0
Chromium	1 - 75	71 - 330	20 - 40	2 - 90
Nickel	1 - 10	92 - 250	unknown	1 - 5
Mercury	<0.01 - 0.2	0.04 - 2.4	0.05 - 0.3	<0.01 - 0.1
Thallium	<0.2 - 0.5	0.7 - 5.1	1.0 - 3.0	<0.1 - 1.0
Zinc	1 - 20	67 - 910	160 - 250	60 - 190

Table 6

Band widths of heavy metal contents in gypsum and anhydrite, given in ppm (g/t)

Elements	Gypsum	Anhydrite
Lead	0.3 - 20	0.4 - 15
Cadmium	<0.2 - 3	<0.2 - 0.3
Chromium	2.8 - 33	1.0 - 9.0
Nickel	unknown	unknown
Mercury	<0.01 - 1.3	<0.01 - 0.02
Thallium	<0.2 - 0.6	<0.2
Zinc	1.0 - 61	5.0 - 22

Table 7

Maximum values for heavy metal contents in concrete and initial materials for concrete, given in ppm (g/t)

Elementes	Initial materials for concrete			Sand
	Concrete	Addition	Gravel	
		Aggregate Cement	Fly ash from bituminous coal	
Lead	260	20	800	100
Cadmium	6	1	4	3
Chromium	130	70	330	100
Nickel	100	10	300	50
Mercury	0.2	0.1	1	0.2
Thallium	4	1	4	2
Zinc	680	50	910	200

Table 8

Mean heavy metal contents in natural rock, given in ppm (g/t)

Elements	Argillaceous rock	Greywacke	Limestone	Granite	Gneiss shale	Basalt	Granulite	Continental crust
Lead	22	14	5	32	16	4	10	15
Cadmium	0.13	0.09	0.16	0.09	0.10	0.10	0.10	0.10
Chromium	90	50	11	12	76	168	88	88
Nickel	68	40	15	7	26	134	33	45
Mercury	0.45	0.11	0.03	0.03	0.02	0.02	0.02	0.02
Thallium	0.68	0.20	0.05	1.10	0.65	0.08	0.28	0.49
Zinc	95	105	23	50	65	100	65	65

2.2 Heavy metal behaviour in concrete

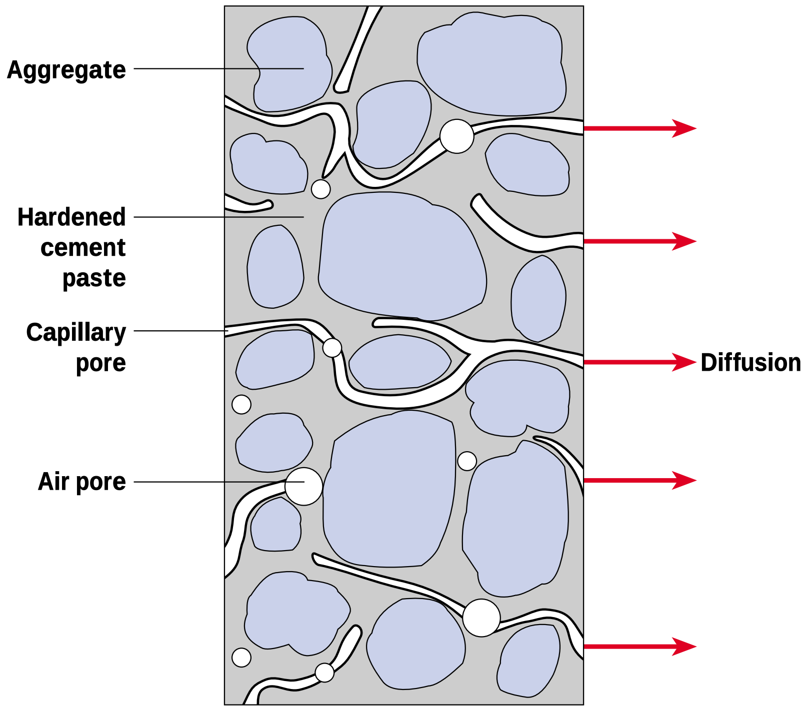


Fig. 7
Stucture of concrete: hardened cement paste, aggregates, capillary pores

The fact that only a small percentage of heavy metals is released from concrete is attributed to the excellent binding capacity of the hardened cement paste. In addition to that, the dense pore structure that concrete has makes it highly resistant to diffusion. This prevents the release of heavy metals dissolved in the pore water of the hardened cement paste (see Fig. 7).

All available investigations corroborate that the release of heavy metals from concrete components is extremely small. Research projects at the Research Institute of the Cement Industry have shown for the elements mercury, thallium and chromium as examples that the values measured in leaching tests lie considerably below those set by the Drinking Water Ordinance even when extremely long leaching times were chosen.

The Figure below shows the investigation results as block diagrams. In one test series the test pieces (4 x 4 x 16 cm³) were stored in drinking water. In another test series drinking water was enriched with lime-dissolving carbonic acid in order to investigate the effects of a severe chemical attack. In a further test series, the test material was doped in order to be able to illustrate leaching with increased heavy metal quantities as well. The leached quantities of the elements under investigation were low both with pure drinking water, chemical attack, and increased heavy metal content.

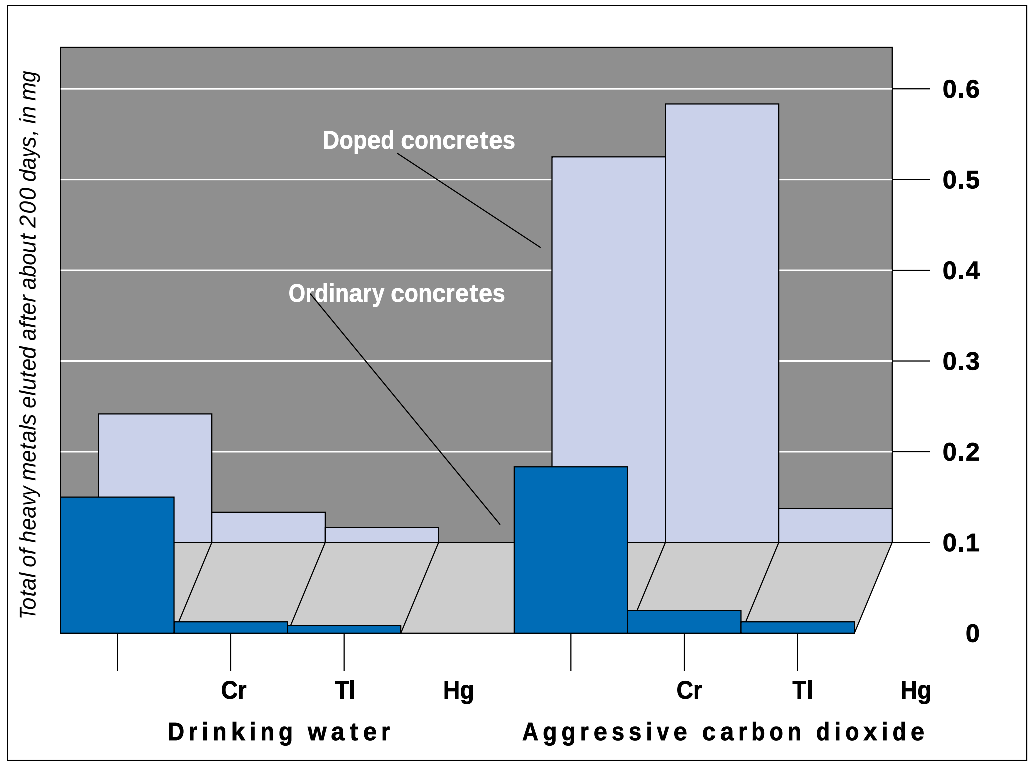


Fig. 8
Comparison of the heavy metal quantities leached from concretes after 200 days

Table 9

Results of a leaching test (DEV-S4) carried out on crushed concrete

Element	Content in cement [mg/kg]	Content in leaching water [mg/l]	Element	Content in cement [mg/kg]	Content in leaching water [mg/l]
As	5	< 0.0002	Mn	500	0.002
Be	1	< 0.0002	Mo	1	0.0004
Cd	< 0.5	< 0.0001	Ni	28	0.002
Co	10	< 0.0002	Pb	17	0.001
Cr	58	0.003	Sb	1	< 0.0002
Cu	22	0.0008	Sn	3	< 0.0002
Hg	< 0.05	< 0.0002	V	66	< 0.0002
Tl	< 0.5	< 0.0002	Zn	310	0.001

Also in these cases, values lay significantly below the limit values of the Drinking Water Ordinance.

The leaching behaviour of heavy metals from used concretes was investigated as well. The recycling of concrete results in its specific surface area getting larger by comminution. The leaching behaviour thus changes with regard to that of solid components.

The table below depicts the heavy metal quantity released from crushed concrete. This is based on a shaking test according to DEV-S4, during which the crushed material is shaken in water for 24 hours. The interpretation leads to the conclusion that the heavy metals are solidly fixed in the hardened cement paste matrix and that the quantities released are tiny. In most cases the concentration found in the leaching water was below the detection limit of the analysis method.

2.3 Release of gases and radioactivity

Table 10

Primary energy consumption and potential effects of selected building materials

Building material		Concrete	Lime sand bricks	Foam concrete		Clay masonry bricks	
						Full	Light
Primary energy	MJ/m³	1750	1410	1610	1370	4180	1760
Potential effects:							
Global warming	kg CO_2 eq	251	227	320	n.i.	n.i.	n.i.
Ozone depletion	kg CCl_3F eq	no contribution	n.i.	n.i.	n.i.	n.i.	n.i.
Acidification	kg SO_2 eq	0.76	0.84	0.92	n.i.	n.i.	n.i.
Eutrophication	kg PO^{3-}_4 eq	0.15	n.i.	n.i.	n.i.	n.i.	n.i.
Photo-oxidants	kg C_2H_4 eq	< 0.01	n.i.	n.i.	n.i.	n.i.	n.i.

Mineral building materials like concrete do not cause any gaseous emissions. Organic constituents that might be liberated in gaseous form can only be introduced into concrete via concrete admixtures or aggregates with organic loads. Various investigations have shown that the release of small concentrations of ammonia or formaldehyde, for example, can only be observed during or shortly following production, if at all. For that reason, application in housing construction is utterly harmless.

Numerous measurements have indicated that the radioactive radiation of concrete is negligible. It is lower than that of natural rocks such as granite and basalt. Differences in the radioactivity of different concrete types solely depend on the aggregate used. The influence that cement and additions such as fly ash exert on the radioactivity of concrete is marginal.

Radon exhalation from concrete is slight as well. It is lower than the average radon exhalation of the natural soil by two orders of magnitude. As a consequence, concrete does not contribute to interior contamination by radon. Quite on the contrary: a concrete floor slab forestalls radon inflow from the soil. By taking corresponding construction measures, residential buildings contaminated by radon that are situated in mining regions of the new federal states have recently been remediated.

2.4 Life cycle assessment

Life cycle assessment constitutes a common tool for analysing environmental impact from an overall ecological point of view. It for instance consists of compiling and assessing the input and output flows of raw material and energy consumption arising when a structure is erected. In addition to that, the potential environmental effects of a product system in the course of its life cycle are evaluated. Globally, the repercussions on global warming and ozone depletion in the atmosphere have to be analysed. From a regional point of view, the effects on soil acidification, the nutrient build-up in water systems known as eutrophication, and the formation of photo-oxidants causing summer smog are investigated. Comprehensive data on concrete has been compiled by now. Table 10 shows the primary energy consumption and other potential effects associated with the production of 1m³ concrete. Corresponding indications for lime sand bricks, foam concrete, and clay masonry bricks serve as comparative values. The data on these building materials is not available in as much detail as that for concrete.

3 Use of alternative fuels in cement clinker production

Many cement works in the Federal Republic of Germany use, or are planning to use, alternative fuels in cement manufacture. By utilizing alternative materials the cement plants improve the cost-effectiveness of the production process. The use of alternative materials in the cement industry simultaneously contributes to the environmentally compatible disposal of a variety of waste materials.

3.1 Input control

However, the cement industry only purposefully uses waste as alternative raw materials and alternative fuels. The material constituents of the waste must comply with the strict quality requirements to be met by the product. It is important that environmentally relevant trace elements do not have any adverse effects on emissions during the cement production process and on the environmental compatibility of the product. For that reason, trace element levels in waste materials have to meet tough requirements. To that end, it might become necessary to strictly limit trace element levels in individual cases.

Quality assurance schemes ensure that all the alternative materials used comply with the requirements for origin and / or constituents. The sampling and testing schedule for input control is determined with respect to each individual alternative material taking into account its composition and bulk size when delivered to the plant. It is jointly laid down by the works and licencing authorities. Testing takes place according to DIN procedures, VDI (Association of German Engineers) codes of practice, and approved waste and residue inspection methods.

3.2 Composition of alternative materials

Raw materials applicable in cement manufacture are mainly substances found in nature, such as limestone, lime marl, clay, sand, or calcium sulfate. Alternative raw materials having SiO_2, Al_2O_3, Fe_2O_3, and / or CaO as their main constituents can be combined with natural raw materials in such a way as to ensure compliance with the requirements both for clinker quality and environmental protection and operational reliability if their distribution is homogeneous. The demands placed on an alternative material primarily depend on the raw material situation prevailing at a certain works. The decisive factor is the quality of the extractable deposits of limestone and lime marl, respectively. The materials used include several substances of the calcium group and corrective materials, such as iron oxide agents or substances providing sulfur and fluorine, respectively.

The table below groups together possible alternative raw materials according to their constituents.

Used tyres (currently about 250,000 t per year) and waste oil (currently about 170,000 t per year) constitute the principal alternative fuels utilized by the German cement industry. To a smaller extent, also fuller earths, wood, plastic materials, and light fractions of domestic and industrial waste are used.
The energy content of alternative fuels is recovered. Just like all fuels, however, they also make a material contribution. Their ashes contribute to the mineral constituents of the cement clinker. The Figure below depicts the ternary diagram for CaO, SiO_2, and Fe_2O_3 plus Al_2O_3. It principally covers the clinker, the composition of which must be precisely adjusted via the feed materials for the cement to obtain its characteristic hydraulic properties.

Table 11

Group classification of alternative raw materials with examples for individual materials

Group classification of alternative raw materials (examples)	
• Ca-Group	- Industrial lime - Lime sludge
• Si-Group	- Used foundry sand
• Fe-Group	- Roasted pyrite - Synthetic haematite - Red mud
• Si-Al-Ca-Group	- Fly ashes - Slags - Crushed sand
• S-Group	- Gypsum from flue gas desulfurization - Chemical gypsum
• F-Group	- CaF_2 filter mud

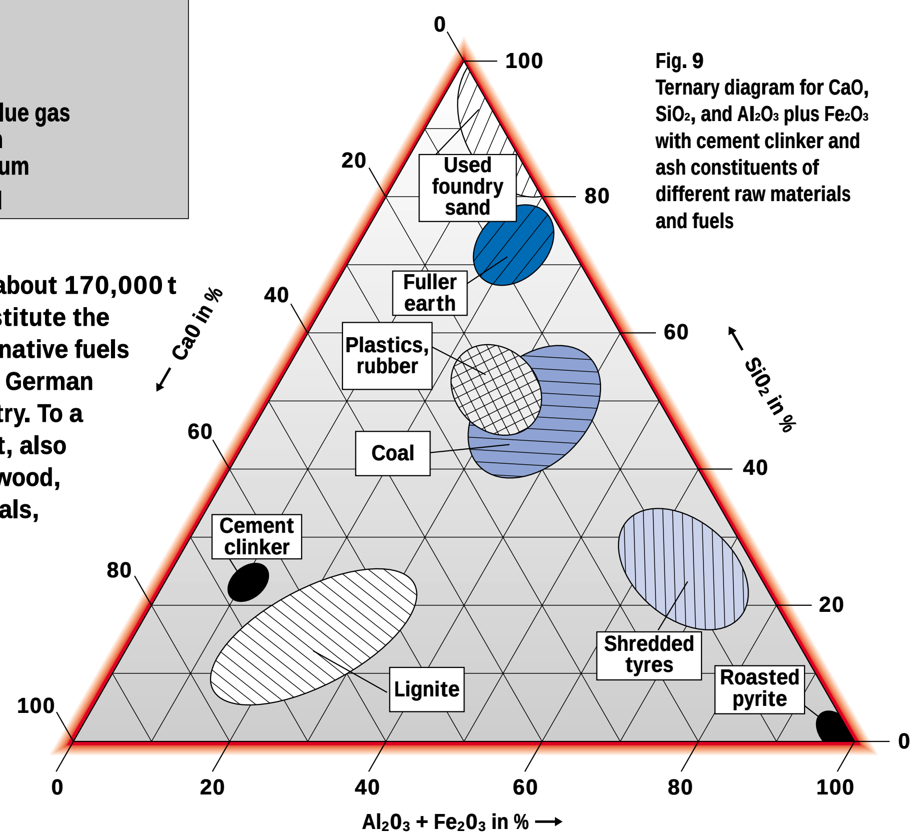
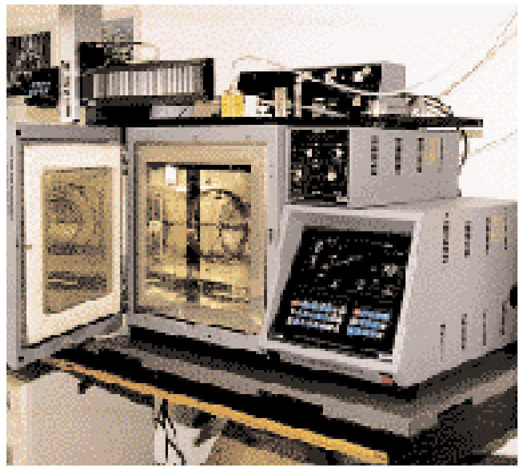


Fig. 9
Ternary diagram for CaO, SiO_2, and Al_2O_3 plus Fe_2O_3 with cement clinker and ash constituents of different raw materials and fuels

3.2 Composition of alternative materials



In addition the ashes of different fuels are depicted. Just like with natural raw materials, their contribution to the raw mix varies depending on their composition and the quantity utilized. In contrast to the procedure in pure combustion systems, the ashes generated are integrated into the product. Otherwise, these constituents would have to be provided via raw materials.

Trace elements are introduced into the clinker burning process via both raw materials and fuels. The use of alternative materials substitutes for an equivalent proportion of natural constituents, which also contain trace elements. The table below summarizes the band widths of elements to be found in the alternative fuels currently utilized in German cement works. Some of the maximum levels (ceiling of the band width) represent

Table 12

Trace element levels in alternative fuels:
typical band widths for German cement plants

Constituent	mg/MJ	Constituent	mg/MJ
Beryllium	<0.01 - 0.1	Tellurium	<0.01 - 0.01
Cadmium	0.01 - 0.7	Antimony	0.03 - 0.05
Mercury	0.01 - 0.1	Lead	0.09 - 25
Thallium	<0.01 - 0.1	Chromium	0.09 - 21
Arsenic	0.003 - 1	Copper	<0.01 - 67
Cobalt	0.02 - 8	Vanadium	0.03 - 16
Nickel	0.1 - 25	Tin	0.03 - 0.7
Selenium	0.03 - 0.4	Zinc	0.5 - 625

voluntary limits self-imposed by operators. Actual values lie significantly below these values in individual cases.

Another Table shows the possible levels, here again for the elements chromium and cadmium, in used tyres, waste oil, plastic materials from the DSD system, scrap wood and refuse-derived fuel (RDF).

The concentrations listed have been normalized on the respective calorific values and

Table 13

Levels in alternative fuels for cement clinker production,
using the elements chromium and cadmium as examples

	Levels in alternative fuels [mg/MJ]	
	Chromium	Cadmium
Used tyres	0.1 - 4	0.1 - 0.35
Waste oil	0.1 - 0.4	0.02 - 0.12
Plastics (DSD)	1 - 8	1 - 2
Scrap wood	0.1 - 6	0.06 - 0.6
RDF	0.6 - 23	0.06 - 0.9

can thus be compared with each other. It becomes apparent that heavy metal concentrations can occur in certain band widths both in alternative fuels and in coal.

A comparison between alternative fuels and so-called standard fuels leads to the conclusion that alternative fuels can have both higher and lower contents depending on the particular circumstances (cf. Table 4).

3

Use of alternative fuels in cement clinker production

3.3 Legal requirements for alternative material use

Cement works are plants that are required to be licenced. Their operation is subject to the provisions of the Federal Pollution Control Act (BImSchG). A licence must be obtained for each individual feed material used, including alternative materials.

The use of alternative fuels is regulated by the 17th Ordinance under the Federal Pollution Control Act (17. BImSchV). The requirements to be met by individual waste materials and their environmentally compatible utilization are laid down in the Waste Management and Recycling Act (KrW/AbfG).

3.3.1 17th Ordinance under the Federal Pollution Control Act

Rotary kiln plants in the cement industry are governed by the 17th Ordinance under the Federal Pollution Control Act (17. BImSchV) if the energy content of waste is recovered in cement clinker production.

If waste is used, emission limit values are considerably lower than laid down in the Clean Air Guide (TA Luft). The limit values depend on the proportion of alternative fuels in the overall fuel energy expended by a kiln system. The higher the proportion of waste, the lower the emission limit values (weighted average calculation). This ensures that the emissions caused by waste incineration do not exceed those stipulated for waste incineration plants.

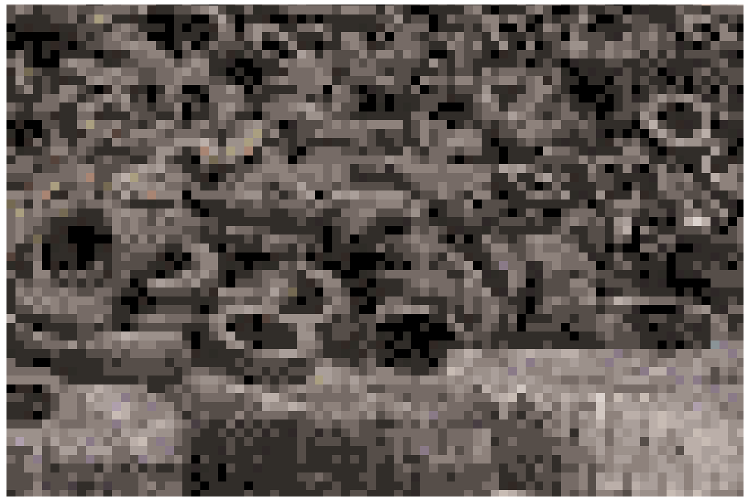
As cement works have to comply with limit values that may sometimes be higher than those applicable for waste incineration plants, critics allege that the use of alternative fuels in the clinker burning process serves to ”fill up” permissible emission concentrations and to ”dilute” pollutant levels. In fact, however, emission concentrations, e.g. of heavy metals, are independent of the feed materials chosen and lie on a very low level. Thus, there is no ”filling up” and ”diluting”. If alternative fuels are used, the actual emission concentrations of heavy metals, for example, are often lower than the concentrations permissible for waste incineration plants. For that reason, the projection of emission loads on the basis of limit values gives figures that do not actually occur in practice. The projection suggests pollution that will, according to the calculation, only diminish if the waste is disposed of in waste incineration plants. This way of proceeding is improper as it deliberately ignores actual facts.

The German Federal Committee for Air Pollution Control (LAI) has specified the requirements of 17. BImSchV for cement plants. For nitrogen oxides, for example, the progressive limit values laid down in the Clean Air Guide have to be complied with as NOx emission concentrations do not depend on the type of fuels used. Cement works have to comply with emission concentrations of 0.50 g/m³ (new plants) and 0.80 g/m³ (existing plants), respectively. Before, the limit values of the Clean Air Guide were almost twice as high.

The requirements for combustion conditions apply both to cement works and to waste disposal plants. To indirectly ensure the burn-out of fuels, organic exhaust gas compounds and carbon monoxide are limited in dedicated combustion plants (waste incineration plants and power plants). In cement works, however, organic exhaust gas compounds and carbon monoxide attributable to the raw materials for clinker production are not subject to these requirements. This does not permit any conclusions about combustion conditions and the toxic organic trace gases that might occur, nor does it imply that rotary kiln plants in the cement industry are exempt from the requirements 17. BImSchV places on combustion conditions. Much rather, the quantity of organic compounds emitted in relation to the quantity of waste used is smaller in the clinker burning process than for example in waste incineration plants.

3.3.2 Waste Management and Recycling Act

The German Waste Management and Recycling Act (KrW-/AbfG) adopts the European concept of waste. A distinction is made between ”product” and ”waste”. According to the terms of the Waste Management and Recycling Act, the alternative materials utilized in the rotary kilns of the cement industry are basically waste. This perception changes if they are produced for the very purpose of being used in cement works – in this case, they constitute products. With waste, a distinction is made between waste materials for recovery and waste materials for disposal. Recovery can pertain both to the material and energy contents. The type of recovery that is more environmentally compatible is given preference.



In cement plants both the energy and the material content of waste is recovered. In addition to that, rotary kiln plants in the cement industry comply with the requirements for combustion efficiency. The principle governing waste disposal is that recovery of waste must take precedence unless disposal represents the more environmentally compatible solution. In this context, the following factors must be taken into account:
- potential emissions,
- preservation of natural resources,
- consumption and generation of energy,
- pollutant enrichment in products, waste for recovery, or products made from them.

3.4 Emissions

Table 14

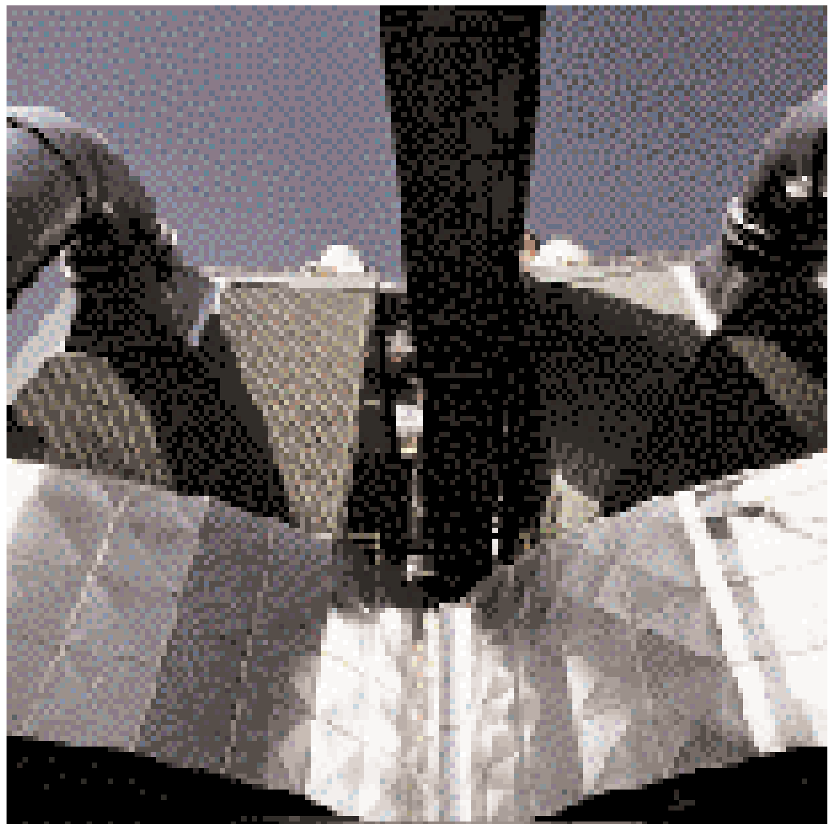
Factors influencing the emission behaviour of different exhaust gas constituents in the clean gas of rotary kiln systems in the cement industry

Exhaust gas constituent	Influencing factor
Dust	Exhaust gas purification
Heavy metals	Exhaust gas purification, input
NO_x	Process
Total carbon, CO, SO_2, NH_3	Raw material
Dioxins and furans	Process

Individual emission components showing similar behaviour in a rotary kiln plant during the clinker burning process can be classed together. The table lists the individual exhaust gas constituents opposite the decisive factors influencing the content of the respective constituents in the exhaust gas. Dust as an emission constituent is influenced by the precipitation behaviour of the exhaust gas cleaning device. The content of particulate heavy metal compositions in the exhaust gas is additionally determined by the input situation in the kiln plant.

The generation of nitrogen oxides is inherent to the process. It is not influenced by the use of alternative materials. The raw material composition is decisive for the content of total carbon and carbon monoxide in the exhaust gas. Moreover, depending on the respective locations, the raw material situation can effect the emissions of sulfur dioxide and ammonia and ammonium compounds. Toxic organic exhaust gas constituents such as dioxins and furans are unaffected by the type of alternative fuels used. Their content in the clean gas of rotary kiln plants is extremely low.

The behaviour of heavy metals on the one hand and dioxins and furans on the other is elaborated on separately below.



Heavy metal emissions

The conditions prevailing during the clinker burning process, which, in contrast to dedicated combustion plants, constitutes a material conversion process, ensure low concentrations of trace elements in the clean gas. This is also true if alternative materials are used. As can be gathered from Fig. 10, emission concentrations produced during the use of alternative fuels for example fall below those according to 17. BImSchV. The Figure illustrates the comparison between the concentrations of trace elements in the clean gas and the respective limit values calculated as so-called "weighted average limit values" according to 17. BImSchV. The alternative material picked was a lightweight fraction of domestic waste. Its share in the firing heat capacity amounted to 25 per cent.

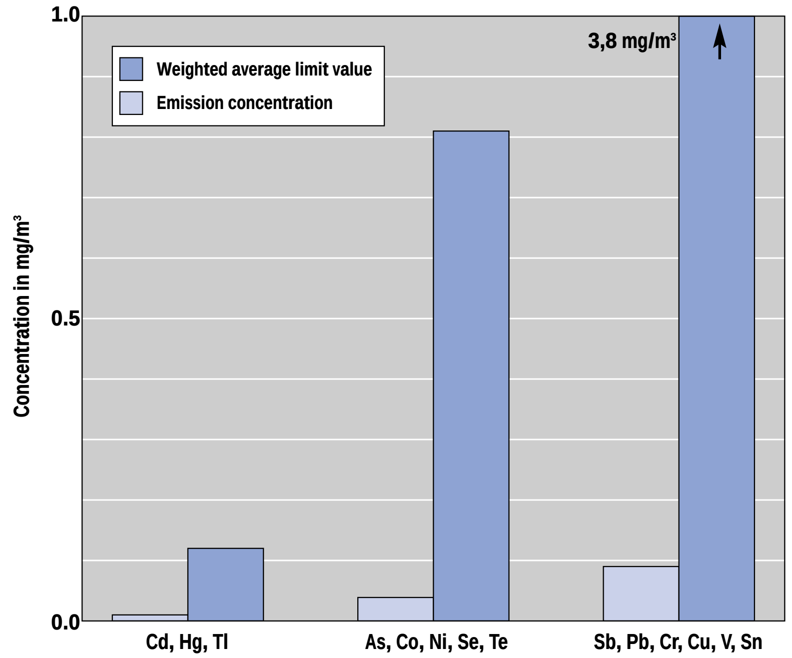


Fig. 10
Comparsion between permissible emission concentrations of individual heavy metals and their average contents in the exhaust gas of a particular kiln plant taken as an example

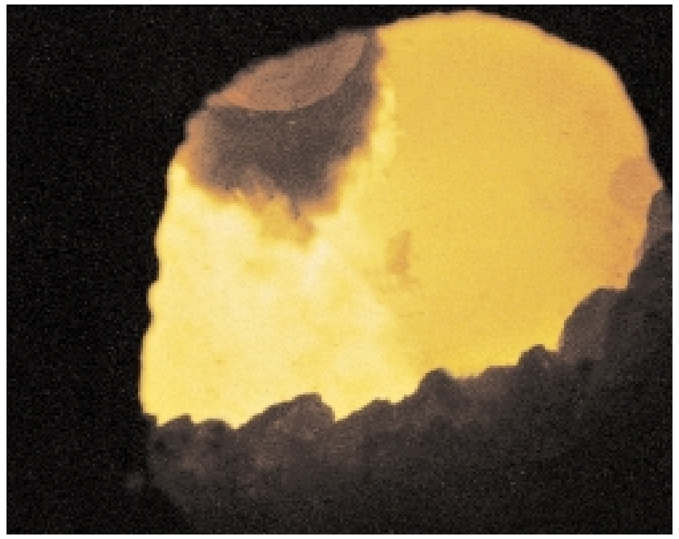
Emission concentrations are based on an input calculation and also allow for maximum contents of elements in the alternative fuels utilized.

The Figure shows that given this input scenario, which is considered pessimum, the values were considerably lower than the emission limit values. This statement also applies to other alternative fuels utilized in cement works. The heavy metal input induced by alternative fuels does not become relevant until levels are significantly higher. Mercury is the only element that may require input to be limited in individual cases.

Dioxin and furan emissions

Dioxin and furan emissions are often discussed in conjunction with the use of alternative fuels. All the emission data compiled by the Research Institute of the Cement Industry and other approved measuring bodies indicate, however, that dioxin and furan emission concentrations are low regardless of the type of fuel used. The Figure below gives all the results the measurements carried out by the Research Institute of the Cement Industry have yielded. The emission concentrations measured are plotted on the ordinate, and about 160 individual measurements are plotted on the abscissa. The alternative use of standard or alternative fuels did not have any effect on the measurement results. All the organic compounds are completely destroyed in the rotary kiln. In addition to that, the use of substitute raw materials did not bring about any alteration in emission concentrations either. All the emission concentrations but one were below the value of 0.1 ng TE / m³ according to 17. BImSchV.

Since the organic compounds contained in the fuels are destroyed completely, the dioxin and furan emissions of rotary kiln plants in the cement industry are very low. For that reason the chlorine content of fuels need not be limited in order to restrict emissions. In contrast to waste incineration plants, moreover, hardly any dioxins and furans are generated in the exhaust gas of rotary kiln plants. No HCl is to be found in the exhaust gas of rotary kiln plants in the cement industry either, and the concentrations of catalytic heavy metals present are low. Furthermore, the residence time of particulates and gases within the temperature range critical for reformation is very short. In contrast to waste incineration plants, rotary kiln systems in the cement industry therefore do not have to be equipped with a special dioxin filter.



Effects of increasing emissions with alternative material use

Critics accuse the cement industry of increasing emission concentrations to such an extent by utilizing alternative materials that the permissible limit values are almost completely exhausted. There is no such "filling up" of limit values. In addition, investigations carried out by the Research Institute of the Cement Industry have shown that the ambient pollution level in the vicinity of a works would lie below the permissible values even if limit values were fully exhausted as purported. Studies on the basis of the limit values laid down in the Clean Air Guide (TA Luft) indicate that the contribution of a cement works to ambient pollution levels lies within one per cent of the concentrations that can be tolerated (Chapter 1.3). This is especially the case for waste utilized in cement plants for energy recovery, as it is subject to the more stringent limit values of 17. BImSchV.

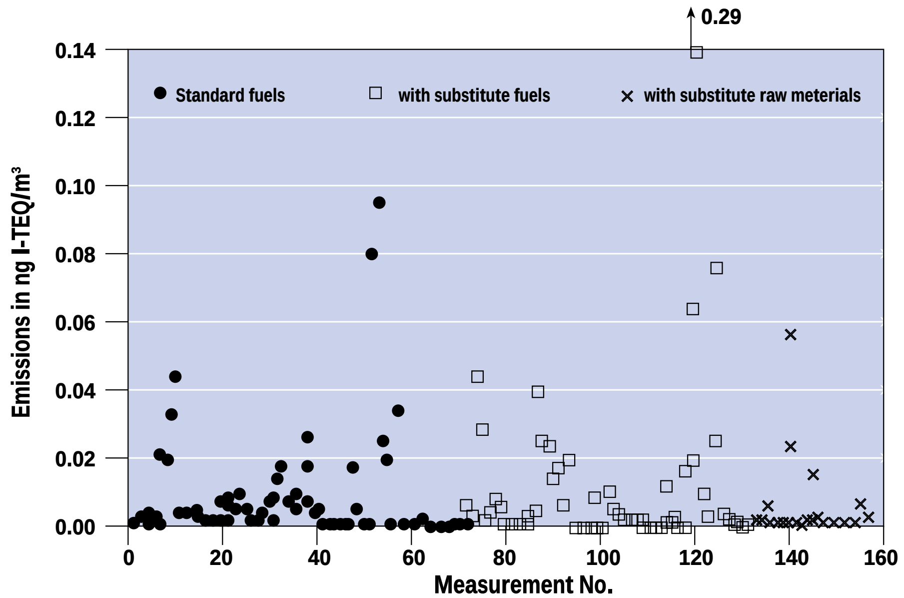


Fig. 11
List of dioxin and furan values measured by the Research Institute of the Cement Industry at rotary kiln plants in Germany up to the summer of 1996

The content of groups of organic substances, such as polychlorinated biphenyls (PCB), polycyclical aromatic hydrocarbon (PAH), polychlorinated naphthalenes (PCN), hexachlorobenzene, or pentachlorophenol, in the clean gas of rotary kiln plants in the cement industry is so low that the contribution to ambient pollution levels falls below the permissible ambient pollution concentrations by several orders of magnitude.

3.5 Preservation of resources

Recovery of material and energy contents

The material conversion process taking place in cement clinker production ensures that both the material and the energy content of waste is recovered in the rotary kiln. The energy content of a waste material is used as combustion heat (energy recovery). The ashes from combustion are necessary mineral constituents of the cement clinker (material recovery). The example of used tyres and carpet remanent demonstrates that the material and energy content of almost all the raw material and fuel constituents is recovered in the clinker burning process. The mineral fuel constituents form clinker minerals. The calorific value of the alternative fuel derives from the remaining organic constituents.

Relative to the organic fraction, the specific calorific value is higher than that of the initial material, since the fraction for material recovery must not be taken into consideration for energy recovery. This is of importance insofar as the Waste Management and Recycling Act stipulates a minimum calorific value of 11000 kJ/ kg for the energy content of alternative fuels to be deemed recoverable.

The simultaneous recovery of the energy and material content in alternative materials distinguishes the clinker burning process from combustion processes in waste incineration and combustion plants. The latter require the discharge of the ashes produced. They cannot be put to further use until they have undergone laborious reprocessing.

Depending on the type of waste, the main focus of recovery in the rotary kiln plants of the cement industry is placed either on the material or the energy aspect, as can be seen from the following examples:

- Waste oil utilization is primarily concerned with recovering the energy content.
- The utilization of used tyres involves recovering both the energy and material content. As iron accounts for about 15% of the steel carcass of tyres, they constitute a material component of the clinker burning process. Conventionally, corresponding quantities of iron ore have to be added to the raw material mix.
- In case of low-clay raw material deposits, fuel ashes from industrial combustion plants (fly ashes, grate ashes) furnish the SiO_2 and Al_2O_3 constituents important for the clinker phases. Material recovery is paramount even though the small content of residual carbon in the ashes contributes to the fuel requirement in clinker production.

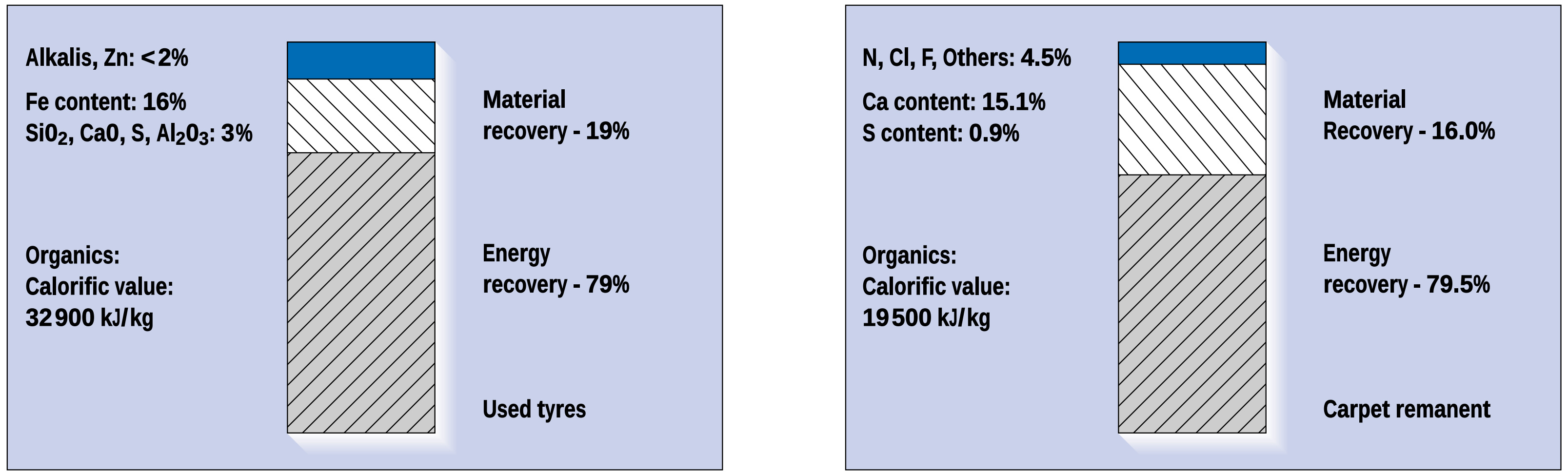


Fig. 12
Utilization of alternative materials in the clinker burning process based on the example of used tyres and carpet remanent

3.6 Energy utilization

CO_2 emissions

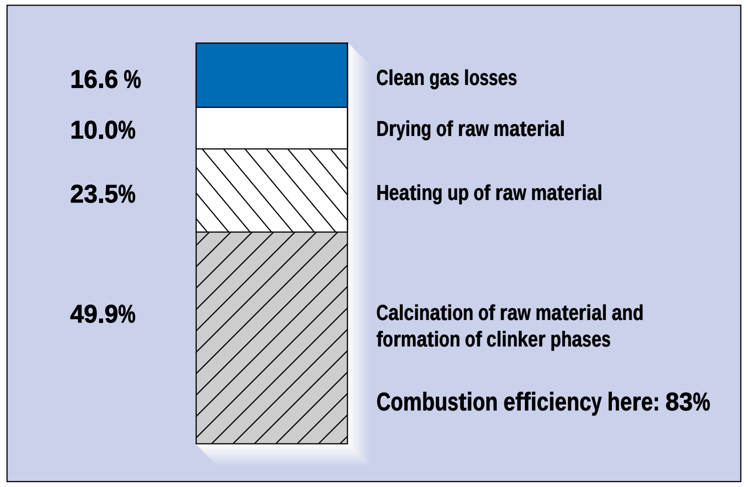
Owing to its process technology the clinker burning process ensures that the energy content of fuels is utilized to a high degree. The process-technology optimization of rotary kiln plants in the past has resulted in a significant reduction in the specific fuel energy requirement for cement manufacture. In addition to that, the German cement industry contributes its share to the reduction of climatically relevant gases by taking various measures aimed at further diminishing its specific CO_2 emissions by the year 2005. The use of alternative fuels can make a vital contribution to reaching this target in the future.

Combustion efficiency

The rotary kiln plants in the cement industry comply with the requirements set up for energy recovery in the Waste Management and Recycling Act. At 80 to 90%, the combustion efficiency of rotary kiln plants in the cement industry is higher than the figure of 75% demanded. The Figure below depicts the various fractions of heat quantity taken into account in calculating combustion efficiency. In the example given, the combustion efficiency amounts to 83%.

Combustion efficiency is calculated in compliance with the preamble to the Waste Management and Recycling Act. It is calculated from the energy expended and the energy lost via the exhaust gas. The fractions used for drying and heating up the initial materials must not be considered losses. This definition applies to all kinds of industrial firing systems. The so-called ”extended combustion efficiencies” cannot be applied to material conversion processes such as cement clinker production. This is an aspect critics of alternative fuel use in cement works like to point to in discussions in order to raise doubts about the combustion conditions prevailing during the clinker burning process.

Fig. 13
Fuel energy distribution in the clinker burning process for the determination of combustion efficiency



3.7 Effects on the product

To be able to assess the effects the use of alternative materials in cement manufacture has on the product, the behaviour of trace elements in the concrete has to be analysed.

Alternative materials can influence the content of trace elements in cement. Their levels may be higher, but also lower than those found if standard materials are used. In practice alternative materials are assumed to behave like standard materials, thus not substantially affecting the trace element content in cement and concrete. As can be seen from 1.3, the heavy metals are fixed in the concrete and thus immobile. All the investigations corroborate that only very small quantities of heavy metals are released from concrete components.

In this context, the effect of alternative material use on the release of heavy metals from finished concrete components was investigated as well. The inputs into a rotary kiln plant were determined for used tyres, waste oil, wood, plastics, and refuse-derived fuels, which alternative materials were selected by way of example. Assuming average heavy metal contents for the alternative fuels, the release from the concrete was measured on crushed material (DEV-S4 method). This presupposes that all the heavy metals dissolved in the pore water are released to a large extent.

3.7 Effects on the product

The results the investigations yielded are illustrated in the Table below. Values turned out to be lower than the limit values laid down in the Drinking Water Ordinance. The use in the clinker burning process of these alternative fuels investigated by way of example does not have any environmentally relevant effects on cement and the concrete made from it. This result is transferrable to other alternative materials as well.

The use of alternative materials in cement manufacture does not impair the environmental compatibility of cement and the concrete made from it. Just as a cement works' contribution to ambient air pollution falls below permissible ambient pollution values, the trace elements releasable from concrete components do not reach environmentally relevant quantities. As a consequence, concrete is an ecological building material. It is environmentally compatible in production and use and can be recycled completely.

Table 15

Effects of alternative material use on the release of heavy metals from concrete bases on the example of selected alternative fuels

	Used tyres	Waste oil	Scrap wood	Plastics	RDF
Firing heat capacity	25%	50%	50%	50%	50%
Trace element content in the fuel (ppm)					
Hg	0.17	0.05	0.2	1.3	1
Cd	8	0.4	3.4	72	1
Tl	0.25	0.1	<0,1	0.3	0.3
Cr	97	10	50	48	40
Pb	410	250	1000	390	160
Zn	15000	500	1500	550	400
Trace element content in the concrete (ppm)					
Hg	<0.01	<0.01	<0.01	<0.01	<0.01
Cd	0.1	0.1	0.1	0.4	0.1
Tl	0.1	0.1	0.1	0.1	0.1
Cr	3.4	3.1	3.6	3.4	3.6
Pb	6.1	5.9	15.5	6.5	6.5
Zn	71.7	21.4	35.2	21.7	23.7
Trace element content in the eluate (mg/l)					
Hg	<0.000001	<0.000001	<0.000001	<0.000001	<0.000001
Cd	0.000002	0.000001	0.000002	0.000005	0.000001
Tl	<0.000001	<0.000001	<0.000001	<0.000001	<0.000001
Cr	0.0021	0.0020	0.0023	0.0021	0.0022
Pb	0.0004	0.0004	0.001	0.0004	0.0004
Zn	0.0045	0.0013	0.0022	0.0014	0.0015

3.8 Concrete recycling

Concrete aggregate can be obtained from old concrete, which serves to recover the material content from concrete components and to recycle the latter into new concrete. The substantial precondition, which is not always easily met at present, is the diligent separation of the concrete from other building materials when a structure is demolished. Only old concrete in its pure form fulfils the prerequisites for high-grade aggregate suitable for re-use.

Concrete made using recycled aggregate also complies with the requirements for an environmentally compatible building material. Recycling does not lead to an enrichment in trace elements that would challenge environmental compatibility. For that reason, surveillance of standard concretes as called for in the set of rules annexed to the Waste Management and Recycling Act is not necessary.

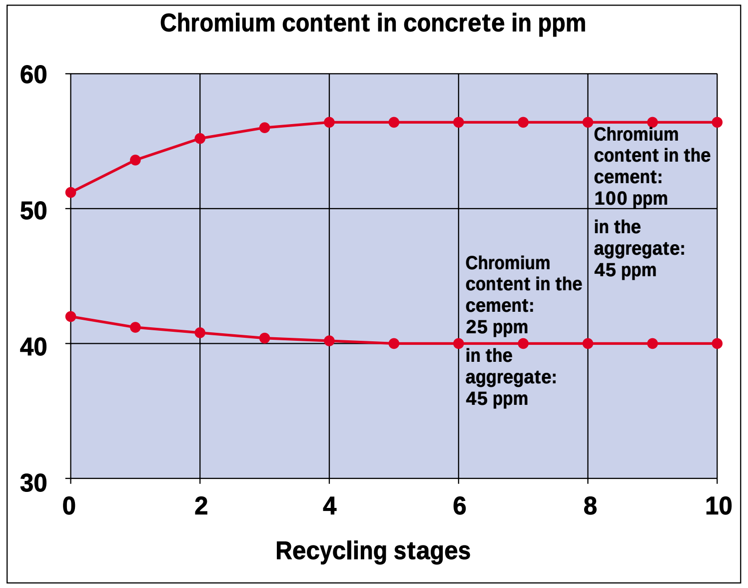


Fig. 14
uses the element chromium as an example to show the influence of repeated recycling on the overall content in concrete (proportion of recycled aggregate in this case: 50%). What is decisive is the contents in the cement and in the natural aggregate used. It becomes evident that the trace element content can both increase and decrease by re-use. In both cases the contents obtained range within the order of magnitude of concrete made using natural aggregate exclusively.

Use of alternative fuels in cement clinker production

3.9 Integrated assessment

The use of alternative materials in the clinker burning process considerably lessens the impact to the environment. Integrated assessments show that this allows the reduction of energy consumption and thus CO_2 emissions. In addition to that, the quantity of waste is diminished significantly.

Life cycle analyses serve to investigate the paths waste materials follow in different methods of utilization and disposal. All the constituent steps are analysed, and the environmentally relevant input and output variables are determined. Initial integrated assessments are available for the use of plastics and waste oil.

Example plastics

Different alternatives for plastics utilization have been studied. If plastics are recycled into chemical products by recovering their material content, their thermal content cannot be recovered in cement works. Standard fuels have to be utilized instead. If plastics are used in the clinker burning process, the chemical products are made from the corresponding constituents of crude oil. If the two methods of recovery are compared, it must be taken into consideration that both cement and the corresponding chemical goods need to be produced (basket of goods). The life cycle analysis determines the most ecological way of producing this basket of goods. There are two options: plastics can either be utilized in a cement plant or, as in the present example, be used in the production of chemical goods.

The Figure below gives the results of a comparative integrated balance based on the examples of CO_2 emissions, energy consumption, and hazardous waste. The comparison covers the use of plastics in a cement works, in a waste disposal plant, in a blastfurnace and for single-material combustion of plastics. Methods for raw material recovery include hydrogenation and the conversion into gaseous or liquid synthesis products.

It becomes evident from the Figure that, as compared to landfilling of the plastic materials, which served as the reference scenario, the use of 1 kg of plastics in a cement plant reduces (i.e. negative figure) the emissions of greenhouse gases, such as CO_2, by about 1 kg (in CO_2 equivalents). This value includes the substitution of coal.

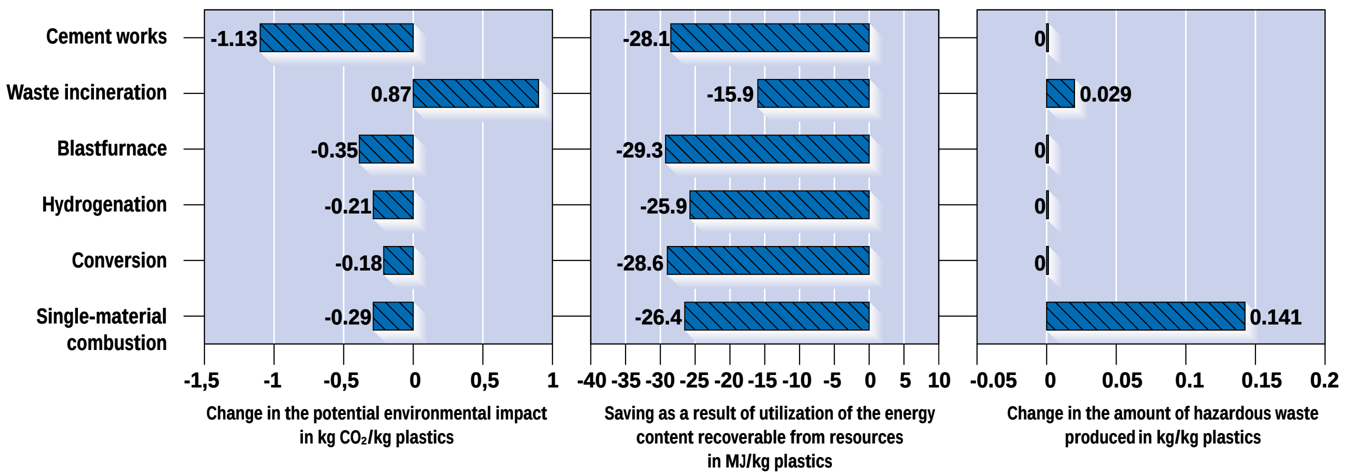


Fig. 15
Integrated assessment of plastic use:
Change in potential environmental impact for various methods of recovery

Pure waste incineration emits 0.87 kg CO_2, as compared to landfilling of the plastic materials. Single-material combustion and methods focused on material recovery and utilization in blastfurnaces only marginally reduce CO_2 emissions.

In terms of the quantity of waste produced and energy consumed, the cement production process also outperforms all the other methods by comparison. It utilizes plastic waste to the extent of 100 per cent. Thus, municipal waste no longer needs to be disposed of. Moreover, no hazardous waste is produced that would have to be tipped at great expense, as is the case with waste incineration plants.

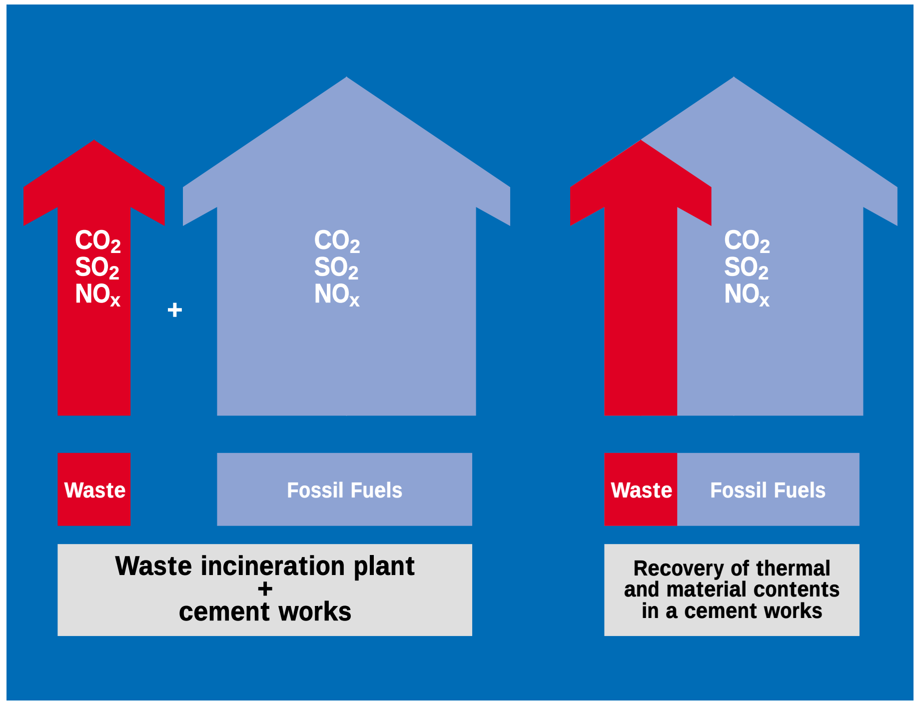


Fig. 16
Emissions and energy consumption during the clinker burning process are largely independent of the type of fuel used. If waste is therefore disposed of in plants installed for that very purpose, or reprocessed in special plants at high energy expenditure, additional emissions occur, causing a deterioration in the life cycle analysis of waste disposal.

Single-material combustion outperforms pure waste incineration, reducing CO_2 emissions by 0.29 kg CO_2 per kg of plastics incinerated. The example of CO_2 emissions underscores that plastics utilization in cement plants is clearly superior to the other methods.

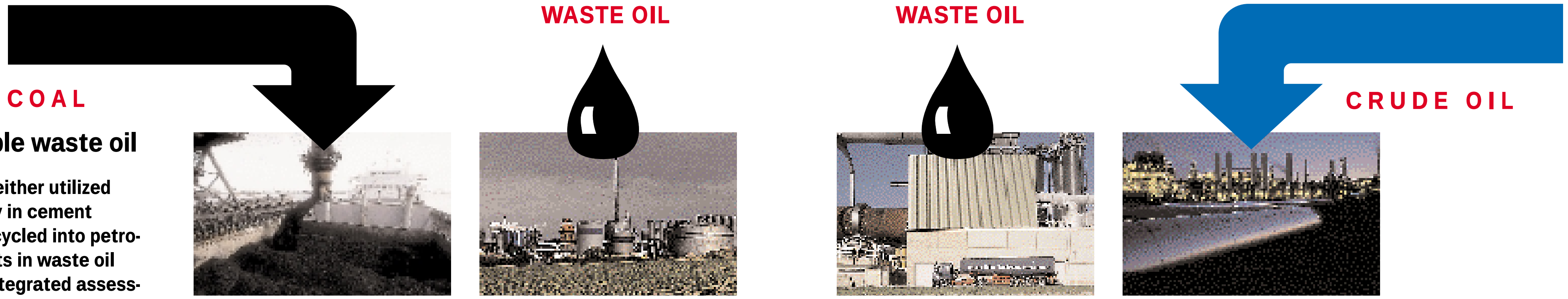
3.9 Integrated assessment

Example waste oil

Waste oil is either utilized energetically in cement works, or recycled into petroleum products in waste oil refineries. Integrated assessment takes into account that it thus substitutes for coal as a fuel in cement works. Recycled waste oil must comply with the specifications applicable for high-grade engine oil.

The Figure depicts the use of waste oil as an energy medium in cement plants in comparison to the reprocessing of waste oil into base oil for lubricant production. This balance takes the entire previous history into account, thus creating the basis for integrated assessment. From the examples of energy consumption and greenhouse gas emission given it becomes evident that waste oil use in cement plants clearly outperforms reprocessing.

Waste oil into REPROCESSING PROCEDURES	Waste oil into CEMENT PLANTS



R E S U L T

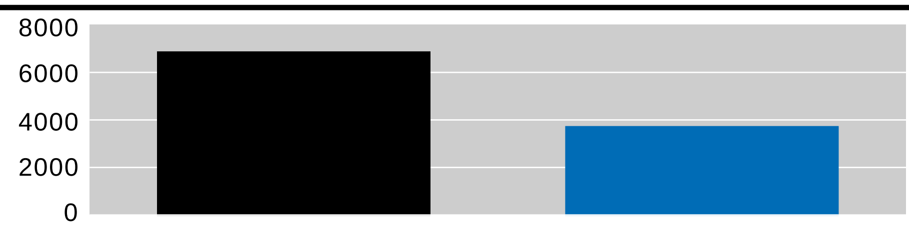
Calorific value	+ base oil + flux oil + lubricating oil	Calorific value	+ base oil + flux oil + lubricating oil

Energy used for obtaining and processing fuel for cement plants and reprocessing waste oil into lubrication oil products (MJ/t waste oil)

Coal: mining and transport	4300
Waste oil refining	2115
Coal in cement plants	462
Total	**6877**

Crude oil: extraction and transport	1434
Primary refining	2676
Waste oil in cement plants	17
Total	**4121**

MJ per t waste oil



Greenhouse gas emission from obtaining and processing fuel for cement plants and repocessing waste oil into lubrication fuel for oil products (kg CO_2/t waste oil)

Coal: mining and transport	551
Waste oil refining	149
Coal in cement plants	4023
Total	**4723**

Crude oil: extraction and transport	124
Primary refining	246
Waste oil in cement plants	2536
Total	**2905**

Kg CO_2 per t waste oil

Imprint

Summary of the '93 to '96 activity report of the Research Institute of the Cement Industry, April 1996, and of the status reports (partly unpublished) of the VDZ / BDZ Commission „Umweltverträgliche Verwertung von Sekundärstoffen“, the „Umweltverträglichkeit zementgebundener Baustoffe“ working group, and the „Recyclingstoffe“ working group.

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