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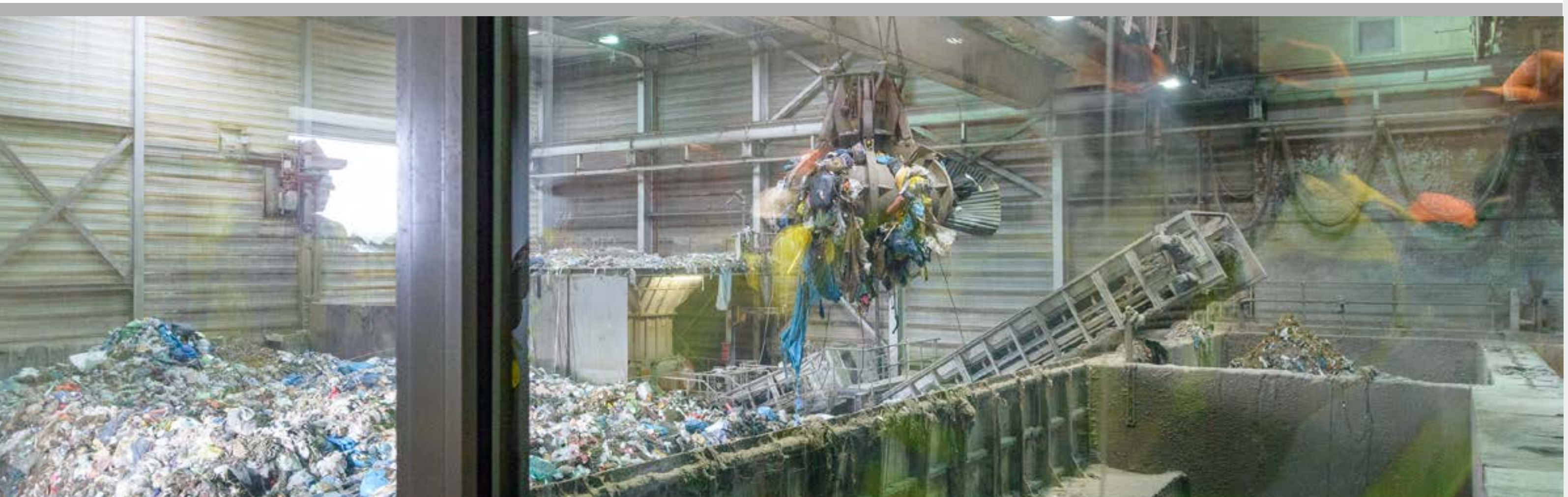

CO-PROCESSING MAGAZINE OF ALTERNATIVE FUELS & RAW MATERIALS

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VISDP: Dirk Lechtenberg | Editorial Director: Dirk Lechtenberg

Dear Readers,

I have been following the alternative fuel developments for more than 20 years. Since the cement industry is a highly capital and energy intensive sector, continuous endeavors during the past three decades have led to employment of waste-derived fuels in cement plants all over the world to cope with energy-related costs.

For example, whilst in 1987 the average thermal substitution rate in Germany was 4.1 %, the following continuous use of various waste-derived alternative fuels now achieved 63.4 % which is some 3.1 million tonnes in 2016. Alternative fuels consist of a broad range of well-treated waste-derived materials.

The prime driver for substituting lignite or coal is the reduction of fuel costs. Cement plants were able to reduce the specific fuel costs down to nil or even achieved "negative" fuel costs by getting gate fees for certain alternative fuels. However, other costs which emerged from adverse effects in connection with the employment of alternative fuels are manifold and have to be considered as well. The worldwide cement industry has become a reliable partner for the waste management sector. The employment of waste-derived fuels for clinker burning is considered the Best Available Technique (BAT) and has contributed to maintain the competitiveness of the local cement industry as well as the conservation of natural resources.

In case you were still wondering why you receive yet another magazine for the cement and lime industry: we think it's about time to focus on alternative fuels and raw materials and we proudly present the first edition of the "Co-Processing Magazine".

In this edition we will give you an overview of the latest developments in alternative fuel use from the worldwide cement industry, as well as market reports from the alternative fuel's markets in the Kingdom of Saudi Arabia.

We will also update you with the programme of our next Alternative Fuel Symposium, which will be on 19 - 21 September.

As a special bonus we will also publish excerpts of the "Alternative Fuels & Raw Materials Handbook for the Cement & Lime Industry" which has been named one of the 10 most important books for the industry.

Please subscribe **here** if you wish to receive your free copy of our magazine on a regular basis and keep updated on everything alternative fuel related.

I hope you enjoy our new magazine and look forward to welcoming you at our next Alternative Fuel Symposium in Duisburg, Germany!

Dirk Lechtenberg

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CO-PROCESSING MAGAZINE OF ALTERNATIVE FUELS & RAW MATERIALS

The evolution of alternative fuels use in the German cement industry

The Evolution of Alternative Fuels Use in the German Cement Industry[1]

Dr. Hansjörg Diller,
MVW Lechtenberg & Partner

1. Summary

Since the cement industry belongs to the capital and energy intensive sector, continuous endeavours over the past three decades have led to employment of waste-derived fuels in German cement plants to cope with energy-related costs. Whilst in 1987 the average thermal substitution rate was 4.1%, continuous use of various waste-derived alternative fuels followed then, and achieved 63.4%, that is some 3.1 m tonnes, in 2014. Alternative fuels consist of a very broad range of well-treated waste-derived materials. The major portion of this, i.e. 1.895 million tonnes, or 61%, consists of fractions of industrial and commercial waste (plastics, paper, textiles) which are mostly two dimensional small-sized particles, also known as "fluff", being highly suitable for kiln burner firing. The prime driver for substituting lignite or coal – being the major standard fuels in Germany – is the reduction of fuel costs. Cement plants were able to reduce the specific fuels costs down near to nil or even achieved "negative" fuel costs which was possible by getting gate fees for certain alternative fuels. However, other costs emerged from adverse effects in connection with the employment of alternative fuels are manifold have to be considered as well.

The German cement industry has become a reliable partner of the waste management sector. The employment of waste-derived fuels for clinker burning is considered the Best Available Technique (BAT), and it has contributed to maintain the competitiveness of the local cement industry as well to the conservation of natural resources.

2. Introduction

The cement producing sector is highly capital as well as energy intensive. In this respect, that sector puts in all reasonable efforts to stay competitive on the local market. Several measures like plant modernisations and process technology optimisations over the last three decades witness the vast endeavours of cement companies to secure the German cement production. The topic of alternative fuels in the German cement industry has gained considerable dynamism over the past years. Rising fossil fuel costs and greater demands on climate-friendly production by using carbon neutral fuels while achieving an unchanged product quality level are the challenges which are linked to the employment of alternative fuels in modern cement production. Fuels are the most featured leverages to reduce operating costs in clinker burning. Since Germany has developed a very well advanced waste management system, cement plants can take advantage of several waste-derived fuels coming out from waste treatment facilities, thus reducing the employment of costly fossil fuels, which is in Germany mainly local lignite and imported hard coal.

The use of waste-derived alternative fuels in the German cement industry has a long tradition. For three decades, German integrated cement plants gathered a plethora of experiences in the substitution of fossil fuels by waste-derived alternative fuels. Continuous use of various waste-derived alternative fuels followed from the mid-eighties in the cement industry in Germany. At that time the thought of cost reduction through replacement of fossil fuels was the priority as considerable competition pressure weighed down on the industry. The employment of alternative fuels has in the meantime evolved into becoming the mainstay in fuel supply.

3. Overview of the German cement industry

German cement industry ranks 15 in terms of global cement production (1). In 2014, German cement production reached around 31 million tonnes of cement (2), that is some 0.74 % of the global cement production, or around 37.2 % of the cement production in the United States (incl. Puerto Rico) (1).

The German cement sector is characterized by a mixture of medium-sized companies as well as global player corporations. Based on figures from 2014 (3), the country has 55 integrated and grinding facilities, operated by 22 companies, as detailed in **Figure 1** and **Table 1**.

[1]This text is based on a lecture given by the author on 15 October 2015 at the "2nd Alternative Fuels Symposium" organised by MVW Lechtenberg & Partner.

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The evolution of alternative fuels use in the German cement industry

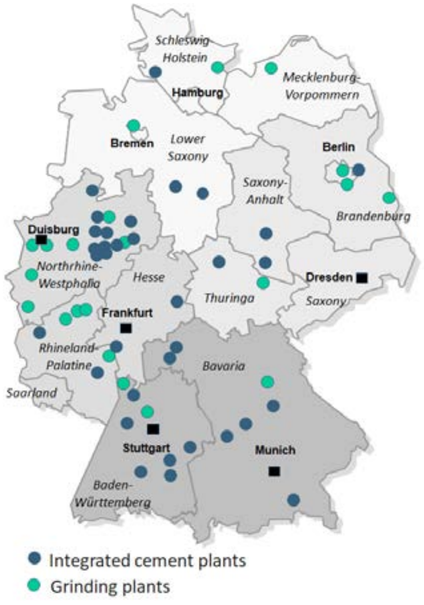

Figure 1 *Map of Germany, indicating the approximate sites of the cement plants (and some cities) within the Federal States.*

Companies	22
Cement plants (integrated and grinding)	55
Employees	7,933
Total turnover	2.5 billion €
Total dispatch of cement	32 million tonnes

Table 1 *Some basic figures for the German cement industry (3).*

The bulk of the sites are located in the Federal State North Rhine Westphalia in the western part of Germany. Another concentration can be observed in the south, the other cement facilities are well distributed over the remaining Federal States.

In 2014, nearly 24 million tonnes of clinker has been produced by 53 kilns. In Germany, 39 cyclone preheater kilns, and 6 Lepol kilns and 8 shaft kilns are active. Amongst the cyclone preheater kilns there are 12 precalcining facilities, 9 of them are equipped with tertiary air duct (4). The average clinker production per kiln is 2355 tonnes. The raw material consumption amounts to approx. 42 million tonnes, that is mostly limestone, marl, clay and sand. Finally, the thermal energy consumption amounts to 92.5 million GJ. **Table 2** summarises the respective key figures.

The cement industry belongs to the energy-intensive industries in terms of both thermal and electrical energy consumption. This sector has been working steadily on reducing the energy consumption. While some 65 years ago, the specific energy consumption was slightly below 7000 kJ/kg clinker, the following years were characterized by improved efficiencies, with wet cement kilns closed in the 1960s to reduce energy consumption. Nowadays, c. 85% of the rotary clinker kilns use the more energy-efficient dry process, and new cement plants are constructed exclusively as cyclone preheater kilns with calciner, tertiary air duct. The modernisation of the integrated cement plants in the newly formed German Federal States after the reunification in 1989, as well as further process technology optimisation in the former Federal States contribute to the very low level of specific thermal energy consumption, which remained more or less stable in the range of 2700 and 3000 kJ/kg cement for around 15 years. The trend in thermal energy consumption is displayed in **Figure 2.**

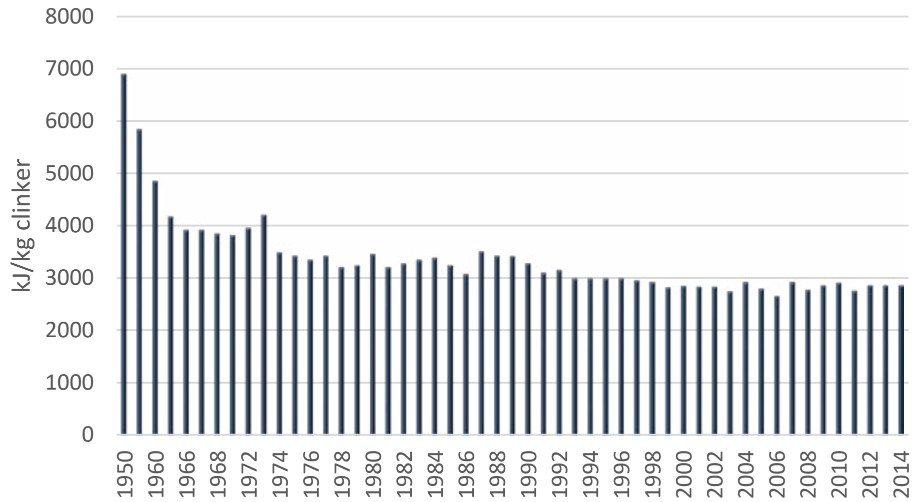

Figure 2 *Trend in specific thermal energy consumption, expressed as kJ/kg clinker; numbers up to 1987 reflect only Western Germany, the following years cover entire Germany; numbers according to (4).*

Clinker production	23.9 million tonnes	
Number of kilns	53	107 160 t/day capacity
Thereof kilns with cyclone preheaters	39	100 460 t/day capacity (93.8%)
Thereof kilns with grate preheaters (Lepol)	6	5 500 t/day capacity (5.1%)
Thereof shaft kilns	8	1 200 t/day capacity (1.1%)
Average clinker production capacity per kiln		2 355 t/day
Natural raw material consumption	around 42 million tonnes	
Thermal energy consumption	around 92.5 million GJ	

Table 2 *Further figures for the German cement industry in 2014 (4).*

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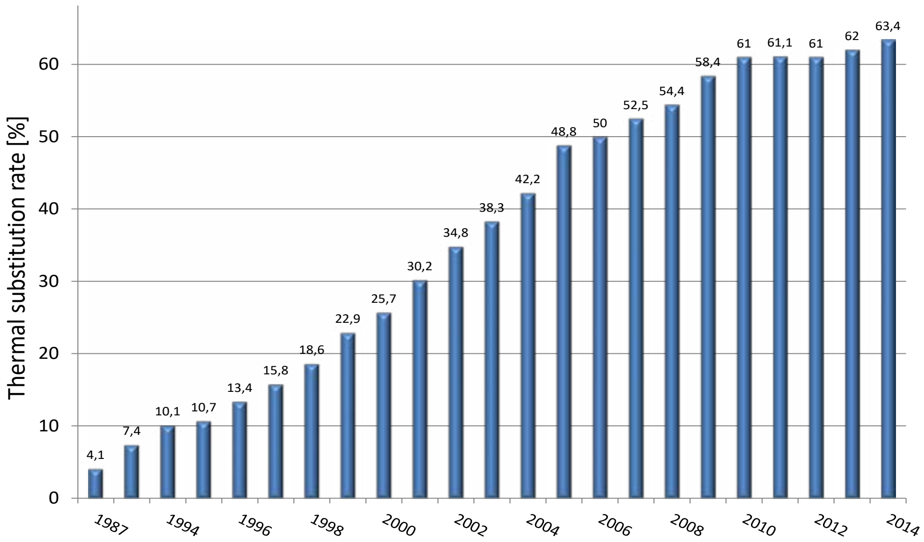

Figure 3 *Average utilisation of alternative fuels in the German cement industry in terms of thermal substitution rate; numbers according to (5)*

	Solid fuels	Liquid fuels	Gaseous fuels
Primary fuels (Standard fuels)	• Hard coal • Lignite • Petcoke	• Light heating oil • Heavy fuel oil	• Natural gas
Alternative fuels (Secondary fuels)	• Tyres – whole/shreds • Rubber • Plastics • Carpet – shreds • Dried sewage sludge • Fuller's earth • Paper residues, paper rejects • Waste wood • Meat and bone meal • Industrial waste • Roofing materials • Bituminous waste	• Waste oil • Spent solvents • Varnish • Animal fat • Organic oils • Organic lubricants • Oil sludge (pasty) • Distillation residues (pasty)	• Lean gas from CFB (circulating fluidized bed)

Table 3 *Compilation of fuels being used in cement plants.*

The evolution of alternative fuels use in the German cement industry

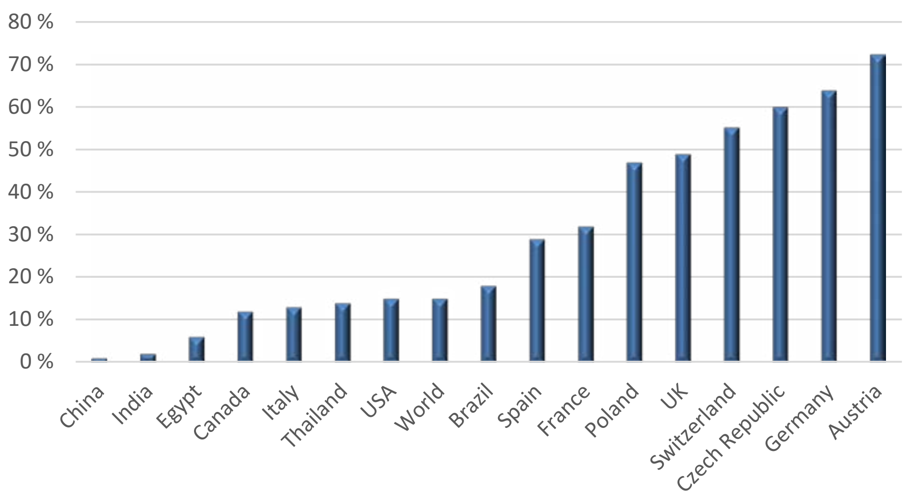

Figure 4 *Average utilisation of alternative fuels in selected countries; numbers according to (6).*

4. Fuels

In the mid-eighties, after carrying out initial trials utilising household-waste as alternative fuels, so-called "BRAM" (Brennstoff aus Müll: fuel from waste) at a Westphalian cement plant, employment of alternative fuels has in the meantime evolved into becoming the mainstay in fuel supply. Since the eighties the German Cement Works Association (Verein Deutscher Zementwerke e.V. (VDZ, Düsseldorf)) has been documenting the use of alternative fuels in the Federal German cement industry. As from 1987 onwards, the numbers as detailed in **Figure 3** show the impressive trend in utilisation of alternative fuels in Germen cement plants. The chart exhibits the usage of alternative fuels has been very advanced over the past 27 years. It should be pointed out that the chart displays average numbers. The range of AF utilisation spans from nil to nearly 100% in German clinker kilns. On global level the thermal substitution rates in European countries are ahead of the rest of the world. **Figure 4** shows the average substitution rates in 2013 for a selection of countries.

The alternative fuel portfolio covers a broad range. **Table 3** lists the fuels being used in cement plants. The presentation divides the kind of fuels by solid, liquid and gaseous. The upper row shows primary fuels, sometimes also assigned as standard fuels. These are all fossil-based. The lower row shows a very many kinds of alternative fuels, also known as secondary fuels. Some of them may be between solid and liquid; they are pasty or sludgy, like paper rejects or oil sludge.

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The "lean gas" is generated in a circulating fluidised bed, which is an integral part of a pre-calciner in a German cement plant.

The cement industry has been working closely with local alternative fuels producers for years, and it became a strong pillar of the local waste management system. The clinker burning process is very sensitive to burning conditions. Hence, the waste-derived fuels have to be treated thoroughly, and in particular, when they are intended for kiln burner feeding. Untreated municipal solid waste fractions are not suited materials for this process. Usually, commercial waste, rejects from production and fractions of high calorific value are separately or jointly pre-processed, that means crushed by shredder, screened and separated by appropriate devices to remove foreign matter, impurities or other harmful constituents. The production of secondary fuels has been described extensively elsewhere, and should not be highlighted in this context. For further reading please refer to, for example (7). Furthermore, the utilisation of waste-derived fuels is strictly subject to environmental laws and regulations. At this juncture, only some examples for further reading should be mentioned here (9 – 10).

Figure 5 shows the evolution of quantities of different types of alternative fuels over the past 16 years. Whilst in 1998 German cement plants used 782 000 tonnes of alternative fuels, the number increased to over 3.1 million tonnes 16 years later, a growth of ca. 300 %. This quantity is equivalent to an energy content of around 58.678 million GJ, which can be translated into a saving of some 2.67 million tonnes of lignite or approx. 2 million tonnes of hard coal.

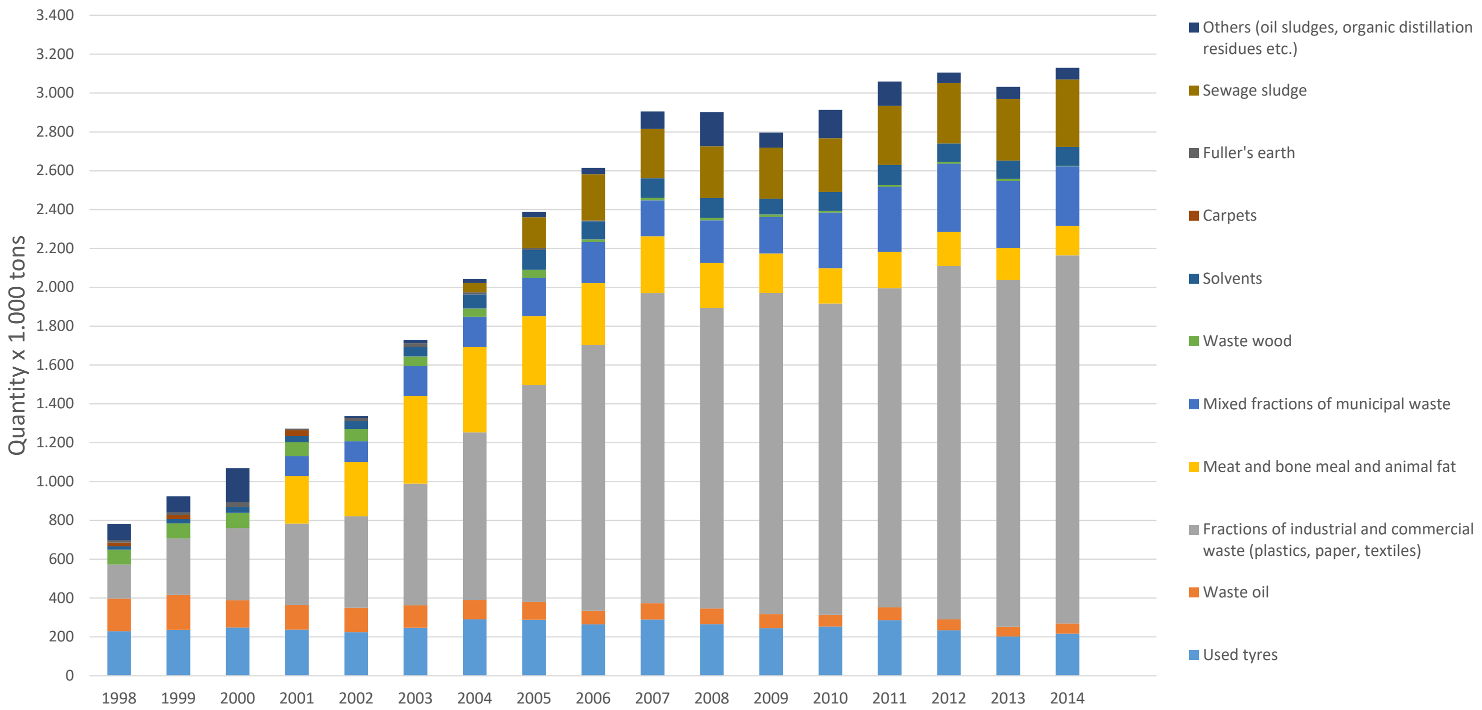

Figure 5 *Presentation of the trend in alternative fuel portfolio in the German cement industry; numbers according to (5).*

The major part of alternative fuels consists of industrial and commercial waste fractions, this is mostly mixed plastics, paper/cardboard, and low portions of textiles. The mostly two-dimensional material is called "fluff" meaning that this material "flies" easily when being injected into the main burner. Since most German cement kilns rely mainly on kiln burner firing, this material with calorific values of approximate 23 MJ/kg became the standard alternative fuel (see **Picture 1**).

Picture 1 *Unloading "fluff" from a Walking-Floor® truck into the storage hall of a cement plant for kiln burner feeding (left); close-up of the fluff (right) (source: MVW).*

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Animal meal (approx. 18 MJ/kg) emerged in 2001 after its feed ban due to mad cow disease, whilst tyres (approx. 28 MJ/kg) have remained more or less stable (see **Picture 2**).

From 2004 onwards, the co-processing of sewage sludge (approx. 8 - 11 MJ/kg) became increasingly important. This is because of the landfill ban in 2005 and regressive sewage sludge disposal as fertiliser in agriculture.

With regard to regular fuels, the German cement plants rely mainly on locally sourced lignite and imported coal, besides some petcoke, oil and gas. Of the 92.5 m GJ consumption in 2014 (10), lignite has the largest proportion of 21.1%, that is equivalent to around 0.89 m tonnes, followed by a 9.6% for hard coal, this is roughly 0.31 m tonnes. As pointed out previously, in 2014 the thermal substitution rate was 63.4%, or 58.6 m GJ (10). "Fractions of industrial and commercial waste" (i.e. fluff) cover the major part of the thermal energy contribution from alternative fuels, namely 42.8% (see **Figure 6**).

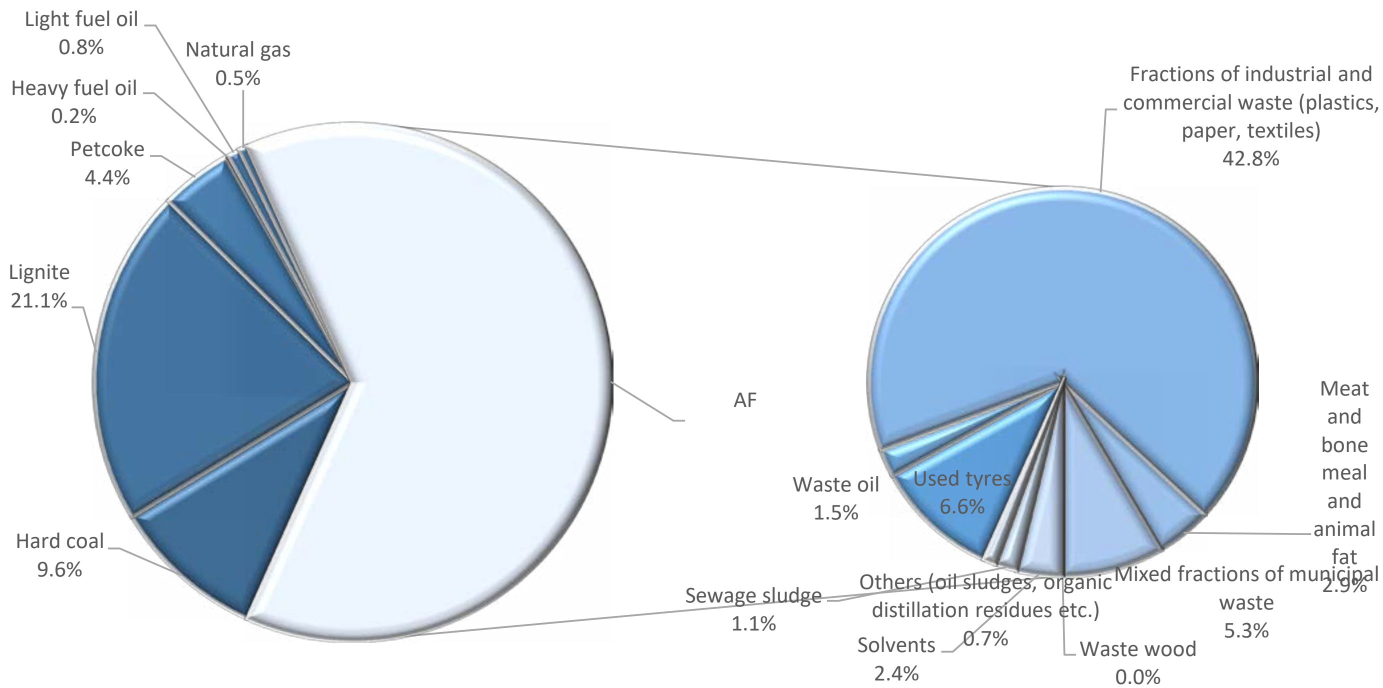

Figure 6 *Breakdown of the entire thermal energy consumption in 2014. Numbers according to (10).*

The evolution of alternative fuels use in the German cement industry

5. Drivers for alternative fuel utilisation

The German cement industry belongs to the energy-intensive sector. Hence, it is particularly dependent on competitive and stable energy policy framework conditions. There is a wealth of drivers in order to cope with energy-connected challenges. The prime driver for using alter-

Picture 2 *Storage of whole tyres for kiln inlet feeding (left); tyre chips for kiln inlet feeding (centre); animal meal for kiln burner fring (right) (source: MVW).*

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native fuels is the reduction of fuel costs. As it is the case for coal, also alternative fuels are subject to market conditions. However, price levels of alternative fuels are, as a rule, far below than those of coal. They can be even below zero. Depending on such gate fees for alternative fuels, several German cement plants achieved “negative” specific fuel costs per tonne of clinker in the 2000s. As an example, **Figure 7** highlights the trend in specific costs versus tonnage of alternative fuels of a cement plant.

In connection with fuel cost reduction also other “side effects” came along, for instance

- the reduction of fossil fuels CO_2 emissions;
- service performance in waste valorisation with accompanying benefits of environmentally compatible valorisation (i.e. avoidance of landfill space, utilisation of energy content);
- the creation of waste valorisation structures for (almost) all types of waste materials;
- the creation and preservation of workplaces;
- and the increase in competitiveness.

The waste management infrastructure in Germany became more and more ready to supply tailor-made alternative fuels, mainly treated fractions of industrial and commercial waste like plastics, paper/cardboard and textiles which became the “standard” AF (fluff).

While increasingly using alternative fuels cement plants experienced a plethora of issues emerged from alternative fuels. Some examples should be discussed here:

The equipment, this is kiln, preheater etc., is subject to increased cleaning efforts. For instance, cleaning of riser duct by manual poking or installation of dozens of blasters in order to remove coatings regularly. Also the AF equipment, in particular the reception bunker is subject to increased cleaning endeavours owing to blockages by large foreign matter within the AF delivery. Cement operators face unexpected kiln downtimes due to cyclone blockages by coating formation due to increased alkali salt circulation. The chlorine loads of alternative fuels result in large amounts of bypass dust, sometimes too much to feed all bypass dust into the cement mill, thus leaving some quantities to be recovered elsewhere.

While using alternative fuels the specific energy consumption per kg of clinker rises, due to higher air demand for combustion and due to higher moisture content of alternative fuels when compared to fossil fuels. Also the kiln burner AF flame is less efficient when compared to a coal or oil flame. In some cement plants, all combined influences resulted in a reduction of clinker production capacity.

Refractories are subject to increased infiltration by alkali salts, deriving from higher chlorine input from alternative fuels. Increased wear and kiln downtimes, means production losses, resulted in additional costs.

These are some examples of detrimental influences emerging from alternative fuels. The costs in connection with these issues are very individual in each case, meaning that each cement plant must calculate its own total cost of fuel substitution.

The evolution of alternative fuels use in the German cement industry

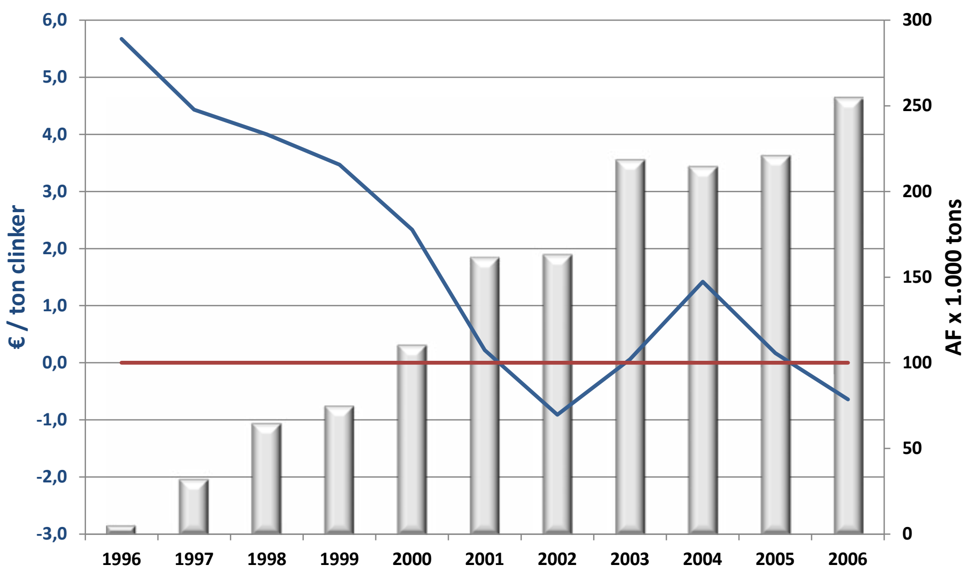

Figure 7 *Trend in entire specific fuel costs (left axis) and utilisation of different kinds of alternative fuels, displayed as summarised columns (right axis) (source: MVW).*

6. Conclusion

The employment of alternative fuels has proven itself in the German cement industry for decades. The proportion of alternative fuels for clinker burning could be increased continuously. In 2014, 63.4% of the average thermal energy demand was covered by various types of waste-derived alternative fuels. Thus, the cement industry has become a reliable partner of the waste management industry along with a significant contribution to the environment. Cement plants are continuous and reliable outlets for treated waste fractions. They can use a broad range of waste fractions which can be recovered thermally without leaving any residues for disposal. Also, cement plants contribute to the conservation of natural resources by using less fossil fuels.

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The prime driver for employing alternative fuels is the reduction of fuel costs. Thus, this kind of fuel contributes to secure the long-term survival of the local cement plants. Last, but not least, the use of alternative fuels in the cement industry is considered as Best Available Technique (BAT) in Europe (11).

7. References

(1) U.S. Geological Survey, Mineral Commodity Summaries, January 2015.

(2) The survey “U.S. Geological Survey, Mineral Commodity Summaries, January 2015” provides an estimated number of 31.0 m tonnes in 2014, whereas the VDZ report “Zementindustrie im Überblick 2015” lists a slightly different number, which is partly estimated, of 32.006 million tonnes

(3) Verein Deutscher Zementwerke e.V. (VDZ): Zementindustrie im Überblick 2015.

(4) Verein Deutscher Zementwerke e.V. (VDZ): Activity Report 2012-2015

(5) Various volumes of “Activity Reports” and “Environmental Data of the German Cement Industry” issued by the German Cement Association VDZ within the range 2000 and 2015.

(6) WBCSD Cement Sustainability Initiative: Getting the Numbers Right. Available at: http://www.wbcsdcement.org/index.php/key-issues/climate-protection/gnr-database. The number for Switzerland has been taken from the report CEMSUISSE 2015: Chiffres-clefs 2014; the number for Austria is from VÖZ: Österreichs Zementindustrie – Vertrauenskrise bremst Investitionen – Jahresbilanz 2014 und Prognose 2015.

(7) D. Lechtenberg, Dr. H. Diller: Alternative Fuels and Raw Materials Handbook for the Cement and Lime Industry. Volume 1 and 2. Verlag Bau + Technik. 2012.

(8) Richard Bolwerk: Waste Incineration and Emission Control by Cement Plants in Germany. 13th World Clean Air and Environmental Protection Congress and Exhibition“, London, UK, August 22 - 27, 2004.

(9) Ministerium für Umwelt und Naturschutz, Landwirtschaft und Verbraucherschutz des Landes Nordrhein-Westfalen: Leitfaden zur energetischen Verwertung von Abfällen in Zement-, Kalk- und Kraftwerken in Nordrhein-Westfalen. 2005.

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(11) European Commission, Institute for Prospective Technological Studies, Sustainable Production and Consumption Unit, European IPPC Bureau: Best Available Techniques (BAT) Reference Document for the Production of Cement, Lime and Magnesium Oxide. 2013.

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Cement and CO_2: How alternative fuels can contribute to a lower fossil CO_2 emission

Cement and CO_2: How alternative fuels can contribute to a lower fossil CO_2 emission

Global production of cement has grown very rapidly in recent years, and after fossil fuels and land-use change, it is the third-largest source of anthropogenic emissions of carbon dioxide.

Most climate scientists agree the main cause of the current global warming trend is human expansion of the "greenhouse effect" — warming that results when the atmosphere traps heat radiating from Earth toward space.

Certain gases in the atmosphere block heat from escaping. Long-lived gases that remain semi-permanently in the atmosphere and do not respond physically or chemically to changes in temperature are described as "forcing" climate change. Gases, such as water vapor, which respond physically or chemically to changes in temperature are seen as "feedbacks." Carbon dioxide (CO_2) is, amongst other gases, such as methane (CH_4), nitrous oxide (N_2O) and chlorofluorocarbons (CFCs) the main force of the greenhouse effect, which is forcing the global climate change.

A minor but very important component of the atmosphere, carbon dioxide is released through natural processes such as respiration and volcano eruptions and through human activities such as deforestation, land use changes, and burning fuels. Humans have increased atmospheric CO_2 concentration by more than a third since the Industrial Revolution began. This is the most important long-lived "forcing" of climate change. Global cement production has increased more than 30-fold since 1950, and almost four-fold since 1990, with much more rapid growth than global fossil energy production in the last two decades. Since 1990 this growth is largely because of rapid development

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Cement and CO_2: How alternative fuels can contribute to a lower fossil CO_2 emission

in China, where cement production has grown by a factor of almost 12, such that 73% of global growth in cement production since 1990 occurred in China (1).

There are two aspects of cement production that result in emissions of CO_2. First is the chemical reaction involved in the production of the main component of cement, clinker, as carbonates (largely limestone, $CaCO_3$) are decomposed into oxides (largely lime, CaO) and CO_2 by the addition of heat. Stoichiometry directly indicates how much CO_2 is released for a given amount of CaO produced. Recent estimates are that these so-called 'process' emissions contribute about 5% of total anthropogenic CO_2 emissions excluding land-use change. The second source of emissions is from the combustion of fossil fuels to generate the significant energy required to heat the raw ingredients to well above 1000°C, and these 'energy' emissions, including those from purchased electricity, could add a further 60% on top of the process emissions (1). Total emissions from the cement industry could therefore contribute as much as 8% of global CO_2 emissions. These process (sometimes industry 'or' industrial processes) and energy emissions are most often reported separately in global emissions inventories.

However, they are several uncertainties regarding the real CO_2 emissions during clinker and Cement production due to following reasons:

a) CaO content in cement
In estimates and analyses done in the 50`s and 70`s , the average CaO content of cement was calculated with 64.1%; therefore the emission factor was calculated with 0.50 tonnes of CO_2 per tonne of cement; as the range of lime [CaO] content in cement is between 60–67 percent, the midpoint of the range was used with 63.5%. Based on this, the Carbon Dioxide Information Analysis Center (CDIAC) is using this CaO content for CO_2 emission calculation. CDIAC's method was directly adopted by the Intergovernmental Panel on Climate Change (IPCC) in their 1996 guidelines and changed in 2006 (3) as "[I]n the absence of data on carbonate inputs or national clinker production data, cement production data may be used to estimate clinker production by taking into account the amounts and types of cement produced and their clinker contents and including a correction for clinker imports and exports. Accounting for imports and exports of clinker is an important factor in the estimation of emissions from this source."

b) Clinker factor
In addition, the IPCC Guidelines now recommend use of a default clinker ratio of 0.75 when it is known that significant amounts of blended cements are produced. If a cement plants uses fly ashes, granulated blast furnace slag or other alternative raw materials, the content of clinker in cement is reduced, which reduces significantly the amout of CO_2 releases from CaO

c) Fossil fuel use
More and more cement plants using alternative fuels instead of fossil fuels. With high substitution rates of 50% and up to 90%, the amount of fossil CO_2 is decreased significantly.

d) Electricity consumption
Using energy efficient drives, reduces the quantity of needed electricity – which is mainly produced by fossil fuels.

The World Business Council for Sustainable Development (WBCSD), through its 'Getting the Numbers Right' initiative, has collected cement data, including clinker production data, directly from firms, but their survey-based approach presents only 22% of the global cement production mainly from international cement groups and doesn't represent the developing markets, especially China, which represents 73% of global growth in cement production since 1990.

The Cement Sustainability Initiative (CSI) has recently published the "Getting The Numbers Right" (GNR) report for 2015, consolidating

		1990	2013	2014	2015
Clinker (grey) volume	Million tonnes	423	643	671	680
Cementitious volume	Million tonnes	512	867	905	916
Gross specific emissions (cementitious)	kg/tonne	761	636	637	634
Net specific emissions (cementitious)	kg/tonne	755	616	615	617
Kiln fuel use	MJ/tonne clinker	4254	3502	3499	3511
Specific electricity use (cement)	kWh/tonne	119	102	101	100
Specific electricity use (clinker)	kWh/tonne		74	74	73
% clinker in cement		83.0	74.9	74.6	74.9
% alternative fuel use		2.0	15.3	15.7	15.9

Table 1 Global data (Source: WBCS) (2)

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information from 939 cement manufacturing facilities (such as integrated plants and grinding centers) (2).

It is shown that within the reporting cement groups, the net CO_2 emissions per tonne cementitious was reduced by 18.3% from 1990 baseline.

CSI reported, that progress was made mainly in replacing less efficient wet and semi wet kiln technologies with more efficient dry preheater and precalciner kiln designs. It further shows, that the specific electricity use in clinker production is on a modest downwards trend.

The theoretical fuel energy demand for cement clinker production is determined by the energy required for the chemical/mineralogical reactions and the thermal energy needed for raw material drying and pre-heating. In the following, we explain the different energy consumption of various kiln types (4):

- Wet process (wet kilns) 5,000 – 6,000 MJ/tonne clinker
- Semi-wet process (Lepol kilns) 3,300 – 4,500 MJ/tonne clinker
- Dry process (suspension preheater kiln) 3,100 – 4,200 MJ/tonne clinker
- Dry process (suspension multistage preheater kiln and Precalciner) 3,000 – 3,800 MJ/tonne clinker

CSI numbers have shown, that it is possible to reduce the CO_2 emissions by using modern technologies (which are more energy efficient), and increasing the use of alternative fuels and raw materials. The upgrade of old, inefficient kilns involves significant investments and long lead times. Therefore, other optimizations which require only minor investments and short lead times are more favorable.

Case study:

In the following, and based on the cement industry in the Kingdom of Saudi Arabia, we are describing the potential CO_2 savings in the Kingdom of Saudi Arabia.

Why Saudi Arabia?

The cement industry in the Kingdom of Saudi Arabia is currently facing a complete change in the economical environment. Up to now, Saudi Arabia's cement companies avail natural gas and heavy fuel oil at a cost of USD 0.75/mmbtu, which is nearly 18% of the YTD 2011 average international market price of USD 4.15/mmbtu. From a financial point of view, no need to use any alternative fuels.

At the same time, the cement plants use, as per national regulations and market conditions, only clinker for cement production, so no need for any alternative raw materials.

The cement production capacity has increased from 25 million tonnes clinker in 2005 to almost 52 million tonnes in 2010. However, the co-existence of some old inefficient kilns, which were built in the late 50's, alongside with new state of the art precalciner kilns, which require low

CO_2 from raw materials (RM)	Clinker production	52 000 000 tpy	
	RM/clinker factor	1.52	
	Raw meal	79 040 000 tpy	
	CO_2	**27 040 000 tpy**	
CO_2 from heavy fuel oil	Emission factor	77.4 t CO_2/TJ	Default, WBCSD CSI
	Total termal energy	195 936.00 TJ	
	CO_2	**15 165 447 tpy**	
CO_2 from electricity	Electricity consumption	110 kWh/t cement	German level
	Cement production	54 736 842 tpy	
	Total electricity consumption	6 021 052 632 kWh	
	CO_2	**757 g CO_2/kWh** **4 557 937 tpy**	CO_2 emissions per kWh generated
Reductive clinker factor	Current	0.85	
	Clinker	52 000 000 tpy	
	Goal	0.75	
	Clinker	37 500 000 tpy	
	CO_2 raw material	19 500 000 tpy	
	CO_2 heavy fuel oil	10 936 620 tpy	
	CO_2 total	30 436 620 tpy	
	Savings CO_2	11 768 826 tpy	

Table 2 *Current emissions and potential savings of CO_2 in Saudi Arabian cement industry (Source: MVW, own calculations)*

energy consumption, is a representative sample to evaluate potential CO_2 savings.

The cement plants producing Ordinary Portland Cement, a strong and very common cement type with a clinker ratio of 0.95.

The CO_2 emissions reported by UNFCCC from IPCC sector 2A1 Cement Production in 2016 are 21.303 million t compared to 9.081 million t in 2009.

All plants use heavy fuel oil and app. 10% of natural gas, resulting in an average energy consumption of 3.900 MJ/kg clinker.

How much CO_2 can be saved?

As Saudi Arabia's primary energy consumption per capita is 3.6 times higher than the world average (at 6.7 tonne of oil equivalent (toe) in 2010 compared with the world average of 1.9 toe), the cement industry offers a wide potential to reduce overall CO_2 emissions while using alternative raw material (such as fly ashes, granu-

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lated blast furnace slag, gypsum sources etc.), alternative fuels (refuse-derived fuels) produced from municipal solid wastes, tyres, and other (also liquid and pasty) waste sources. Especially waste from the oil exploration and processing industry (drilling waste, refinery wastes) are widely available.

Alternative raw materials

If the cement industry in Saudi Arabia were to use alternative raw materials to achieve a clinker factor of 0.75, this would save a total of more than 11 million t of CO_2/year (Table 2). However, in order to reduce the clinker factor to 0.75, sufficient fly ash and granulated blastfurnace slag must be available. As in Saudi Arabia, electricity is not produced in coal-fired power plants, the maximum alternative raw material substitution is limited to available waste sources.

AFs

Cement plants can achieve a substitution rate of 60% AFs in countries where an infrastructure for the collection and processing of waste into RDF is available. CSI members reported a substitution rate of only 15.9% in 2016; however, this is mainly dependent on the available waste management infrastructure. In Saudi Arabia there is no such infrastructure for the production of AFs. However, all waste is currently collected and landfilled. To achieve a 60% substitution rate, a quantity of 6 million tonnes of RDF with a calorific value of 4500 kcal/kg is needed.

Influence on economics

Fuel costs in Saudi Arabia are subsidised by the government. Currently one tonne of fuel oil is delivered at around USD 40 to the cement plants. With such low fuel prices, nobody has the intention to switch. The government has now implemented a Saudi Mandatory Energy Efficiency Program and has already started to increase the fossil fuel prices. At the end of 2017, the gasoline price was increased by 80% and it is anticipated that Prince Muhammad bin Salman will stop the subsidies to the local industry and increase the fossil fuel price to a world market level by 2019.

At the same time, the government is implementing a Strategy for the Improvement of Solid Waste Management in Saudi Arabia, to be implemented this year, which will give guidelines for a sustainable waste management, including the production and use of RDF for the municipalities.

The production of RDF, depending on the involved technology, costs about USD 25 – 40 / tonne. Only with increasing fuel costs and recycling fees from the government can the cement industry introduce AFs. With all these measures, it is foreseen that the implementation of RDF will become a major driver for the industry to save costs.

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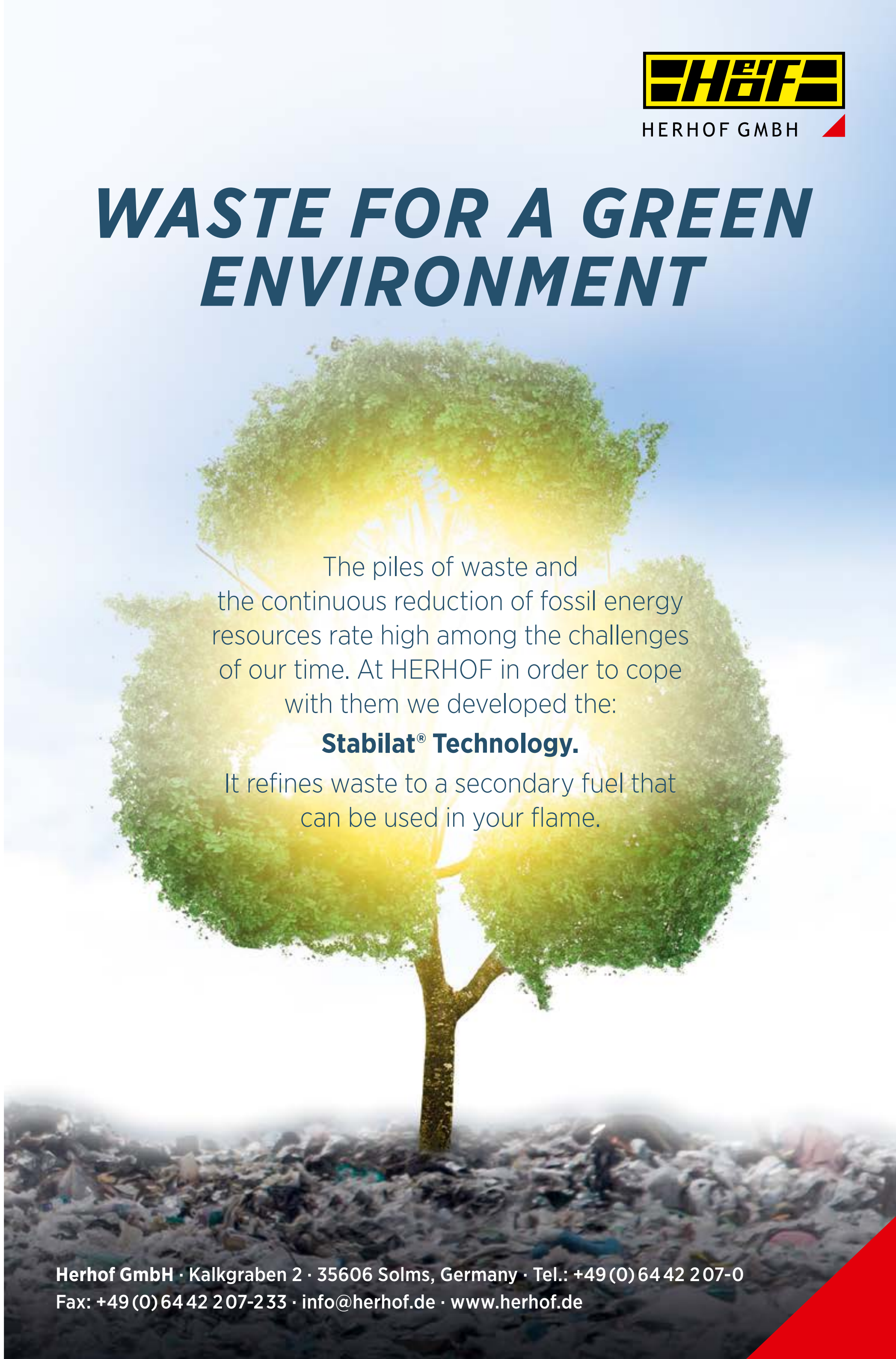

NEWS

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- Ireland: Irish Cement to be allowed to replace fossil fuels at two plants
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- 'Invisible' cement polluters urged to double climate efforts
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- PPC to expand its alternative fuel initiative in SA

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IFAT 2018

MVW Lechtenberg & Partner participates in the IFAT, a world‘s leading Trade Fair for Water, Sewage, Waste and Raw Materials Management, 14-19 May in Munich.

Please visit us at the joint booth of the “Deutsche Gesellschaft für Abfallwirtschaft e.V. (German Waste Management Association) in **Hall A6 booth 229**

On 15, 16 and 17 May, at 4 p.m. each of these days, Dirk Lechtenberg will give a presentation on “RDF from municipal solid wastes - growth potential and new technical opportunities“ at the booth of the company Eggersmann, Germany, at B5.427/526

Visit us at Eggersmann

IFAT World's Leading Trade Fair for Water, Sewage, Waste and Raw Materials Management
May 14–18, 2018 | Messe München

Ireland: Irish Cement to be allowed to replace fossil fuels at two plants

Proposed Limerick and Meath developments were opposed by environmental groups.

The Authorities‘ decision has been criticised by Limerick against Pollution (LAP), which was critical of the plant’s environmental record and a proposal to burn used tyres in kilns used in the manufacturing process at an oral hearing last September. The decision upholds permission granted by Limerick City and County Council to allow the €10 million project to proceed. Irish Cement’s plans are to increase the amount of alternative fuels used in Mungret Factory. It has been using up to 120,000 tonnes a year of residual waste including textiles, plastics and wastepaper to fire its kilns there, and was seeking permission to increase the volume of waste to up to 600,000 tonnes. Irish Cement has always maintained its plans do not pose any threat to the local environment. It said the development “is essential to ensure the long-term viability of the Mungret factory, which is currently the only cement factory in Ireland not using alternative fuels and one of the last in Europe not to be availing of these fuels”.

It said the development would protect its current workforce of 80 and create further jobs.

Welcoming the Authorities‘ decision, Irish Cement stated: “Replacing fossil fuels in cement factories is standard practice throughout Europe, and is in line with European, national, and regional waste management policy. Irish Cement already uses alternative fuels in our sister plant in Platin, Co Meath”

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IEA, CSI cement technology roadmap outlines path to cutting CO_2 emissions 24% by 2050

A combination of technology and policy solutions could provide a pathway to reducing direct carbon dioxide emissions from the cement industry by 24% below current levels by 2050, according to a new report by the International Energy Agency (IEA) and the Cement Sustainability Initiative (CSI).

The technology roadmap—Low-Carbon Transition in the Cement Industry—updates the first global sectoral roadmap produced in 2009. It aims to identify and develop international collaborative efforts and provide evidence for public and private sector decision-makers to move towards a more sustainable cement sector that can contribute to long-term climate goals.

The cement sector is the third-largest industrial energy consumer in the world, responsible for 7% of industrial energy use (10.7 EJ), and the second industrial emitter of carbon dioxide, with about 7% of global emissions. As a flagship sectoral project of the World Business Council for Sustainable Development (WBCSD), the CSI is a global effort currently gathering 24 major cement producers having operations in more than 100 countries and who have integrated sustainable development into their business strategies and operations.

'Invisible' cement polluters urged to double climate efforts

Cement companies need to "more than double" their emissions reductions if they are to limit global warming to below 2°C, in line with the UN's climate goals, according to new research by CDP, a UK-based research organisation pushing for greater transparency in the way companies communicate environmental performance to investors.
Cement is the second most polluting industry after steelmaking and is used in concrete, which after water is the most consumed product in the world, CDP pointed out. However, the sector has so far remained largely below the radar.
"Cement is a heavy and largely invisible polluter, yet taken for granted as a necessary building block of basic civilisation," said Paul Simpson, the CEO of CDP.
This could change. The cement industry itself accounts for only 6% of global CO_2 emissions. But the built environment, which includes offices and residential buildings, uses concrete extensively and accounts for over a third of global emissions, the report pointed out, suggesting pressure may in future come from downstream users of cement.

Namibia: Ohorongho Cement

"Ohorongo Cement is one of the very few companies in Southern Africa that received environmental certification according to the revised 2015 standards. The company successfully received its ISO 14001: 2015 certification, which confirms its continued commitment towards sustainability and caring for the environment. Furthermore, the company is in compliance with all its licences with Namibia's Environmental Management Act of 2007 while the environmental impact assessment processes for all the projects were completed," Hans-Willem Schütte, the Managing Director of Ohorongho Cement enthused during a media tour of the company in April 2018. Since the commissioning of the plant in 2011, it has started to make use of wood chips, charcoal fines, and refuse derived fuels to supplement the use of environmentally unfriendly fossil fuels like coal, which need to be imported from neighbouring countries like South Africa and Botswana. They are also in the construction phase of a 5MW solar plant, which is expected to go into operation by July this year.

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PPC to expand its alternative fuel initiative in SA

JOHANNESBURG - PPC, the listed cement and lime producer, is planning to expand its alternative fuel initiative in South Africa as part of the company's profit improvement programme.

PPC chief executive Johan Claassen said they were already doing tyre burning at PPC's De Hoek plant in the Western Cape and the next step was refuse-derived fuel.

Claassen said this involved burning "fluff" and they had started with the separation and sorting of refuse in the Cape Peninsula and would be taking and using a certain fraction of that as an alternative fuel for the De Hoek cement kilns.

Claassen said the City of Cape Town, Drakenstein, which included Wellington and Paarl, and Swartland, which included Malmesbury, were out of landfill space and had to do something.

"So waste burning in the Western Cape will become a reality very soon. We have engaged with all the necessary parties and have a domain expert from Germany that can assist us and went through this process before," he said.

Claassen said PPC had also saved costs at the De Hoek plant by conserving about 40 percent of the water used by the plant.

He said these initiatives formed part of PPC's cost optimisation programme, which was focused on cost savings and revenue enhancement.

Claassen said it was already under way and aimed to deliver targeted savings of R50 a ton as part of PPC second phase profit improvement programme.

He was hopeful PPC would realise something tangible from the initiative in the next 12 to 18 months.

Claassen was not concerned about any disruption to the supply of waste tyres that were burnt in the kilns at the De Hoek plant because of the liquidation of the controversial Recycling and Economic Development Initiative of South Africa's (Redisa), the only government-approved integrated waste tyre plan.

The Western Cape High Court in September placed Redisa and its management company Kusaga Taka Consulting in final liquidation and granted an order for Redisa's assets to be transferred to the Waste Management Bureau.

PPC, is planning to expand its alternative fuel initiative in South Africa as part of the company's profit improvement programme. Photo: Supplied

Attorneys for Redisa gave notice of their intention to appeal the entire order granted by Judge Robert Henney in the Western Cape High Court.

In a 101-page judgment, Judge Henney said there had been "an unlawful misappropriation of public funds" by the Redisa directors Herman Erdmann, Stacey-Inger Davidson and Charline Kirk through Kusaga Taka to Avranet and Nine Years Investments as well as by Kirk and Kusaga Taka chief executive Christopher Crozier through Nine Years Investments.

Claassen said PPC had seen "this coming" and had built up serious tyre stocks at the De Hoek plant and also had a site at Vissershok in the Cape where it had quite a big stock of waste tyres.

Source: Businuess Report, Roy Cokayne

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It is my great pleasure to invite you to the 5th Alternative Fuels Symposium on 19 - 21 September. We are delighted to announce that this year's event will include a prize giving for the Alternative Fuel Award" to recognize the best three practices in alternative fuel production and use.

Another highlight of this year's programme will be the exclusive insights from top cement producers such as City Cement (Kingdom of Saudi Arabia), Geocycle APAC, Portland Cement Association (USA) and others explaining case studies and their first-hand experience on how to develop and run a successful waste to fuel project. The programme will also include an optional site visit to the Portlandcement Plant Wittekind, Hugo Miebach & Sons in Erwitte which process its own refuse-derived fuels from municipal solid waste, commercial and industrial waste.

Alternative Fuel Symposium, 19 – 21 September

Confirmed speakers (as of 15th April):

- **Rick Bohan**, Director of Manufacturing Technology, Portland Cement Association, USA: "Development of Alternative Fuels in the United States of America"
- **Saleh Al Shabnan**, CEO of City Cement, Kingdom of Saudi Arabia: "The Role of the Cement Industry in a Sustainable Waste Management in the Kingdom of Saudi Arabia - Constraints and Opportunities"
- **Berthold Kren**, Region Head of Geocycle Asia, GM - Geocycle India: "Development of Alternative Fuels in the APAC Region - Case Studies of Geocycle"
- **Bassam Moumneh**, CCO of AVERDA International, United Arab Emirates: "Waste management in selected countries in Middle East and Africa – opportunities and business models for alternative fuels" (Preliminary title)
- **Dr. Rainer Bertling**: Aumund Fördertechnik, Germany: "Aumunds Alternative Fuel Approach" (Preliminary title)
- **Konstantinos Papadimas**, Managing Director of Herhof, Germany: "From municipal solid waste to an alternative fuel resource by Herhof "Stabilat©" Technology"
- **Robert Krist**, FLS Pfister, Germany: "Case studies of weighing and dosing alternative fuels from Germany, UAE and Spain"
- **Leos Volesky**, Schenck Process, Germany "New developments in alternative fuels" (Preliminary title)

Furthermore, by the beginning of May the committee will review all applications for the "Alternative Fuel Award". We have received almost 20 applications from cement plants and RDF producers from all over the world in which particularly interesting alternative fuel projects are described. The three winners will present their case studies in the symposium.

Besides this, equipment suppliers and service providers will present case studies from their projects and explain new developments.

I look forward to welcoming you to the 5th Alternative Fuels Symposium in Duisburg.

Dirk Lechtenberg, MVW Lechtenberg & Partner.

As you can see, there is a lot to look forward to. If you would like to participate as well, please [register here]

5th Alternative Fuel Symposium organised with the support of

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Raw materials: Power plant ashes as substitute raw material

“Ashes from power plants” – huge potential for cement producers to reduce carbon emissions and save costs.

Dirk Lechtenberg explains the use of power plant ashes as alternative raw material for the cement industry

Ashes derive from the combustion of solid or liquid fuels in power plants producing heat and/or electricity. Ashes consist predominantly of inorganic material and small portions of organics due to incomplete combustion. The compositions of ashes are strongly dependent on the fuels, the combustion technique and the combustion process control. Hence, the ash composition varies over a wide range.

Ashes or Coal Combustion Products (CCP) are categorised in groups, each based on physical and chemical forms derived from coal combustion methods and emission controls:

Fly ash (FA) is a fine powder, which is mainly composed of spherical glassy particles. It is produced by electrostatic or mechanical precipitation of dust-like particles from the flue gases of furnaces fired with coal or lignite at about 1,100 to 1,400°C. There, siliceous and calcereous fly ashes with pozzolanic and/or latent hydraulic properties are produced which depend upon the type of boiler and the type of coal [E-1]. Fly ashes from coal-fired power plants can be categorised into the European Waste Code 10 01 02.

On the other hand, (furnace) bottom ash (BA) is a granular material removed from the bottom of dry boilers. This is much coarser than FA though also formed during the combustion of coal [E-1].

Further, boiler slag (BS) is a vitreous grained material deriving from coal combustion in boilers at temperatures of 1,500 to 1,700°C. This process is followed by wet ash removal of wet bottom furnaces [E-1]. Bottom ashes and slag can be categorised into the EWC 10 01 01.

Fluidised bed combustion (FBC) ash is formed in fluidised bed combustion boilers. This technique combines coal combustion and flue gas desulphurisation in the boiler at temperatures of 800 to 900°C [E-1]. This material can be categorised by the EWC 10 01 24.

From left to right (Source: MVW): Picture 1 *Wet ash from a German lignite power plant,* ***Picture 2*** *Wet ash from a German hard coal power plant,* ***Picture 3*** *Fly ash from a hard coal power plant,* ***Picture 4*** *Hard coal power plant: Cooling towers on the left, generator, boiler house and other facilities on the right hand side*

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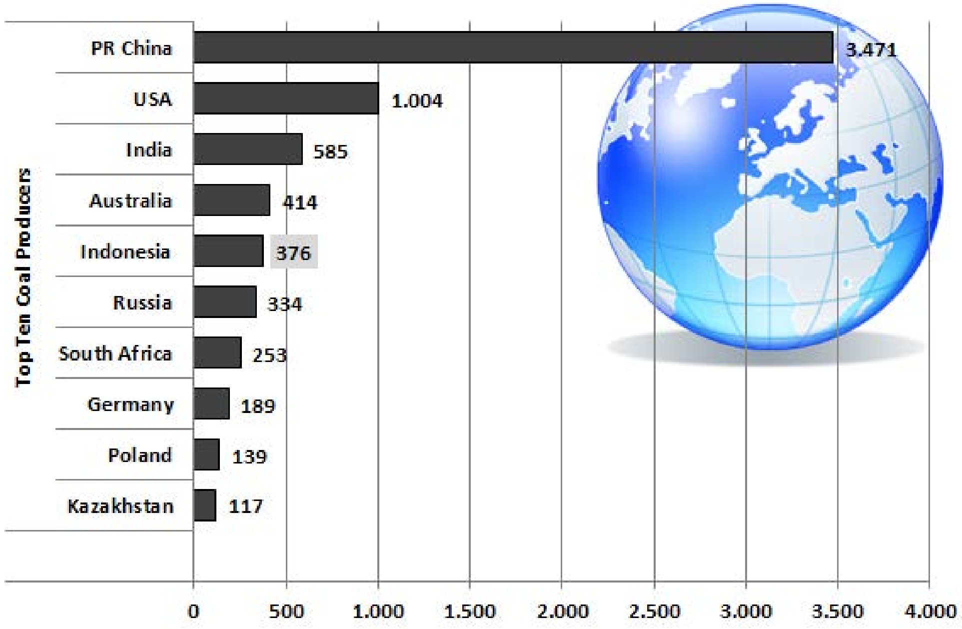

Figure 1 *Top ten lignite producers (in million tonnes) according to [W-1]*

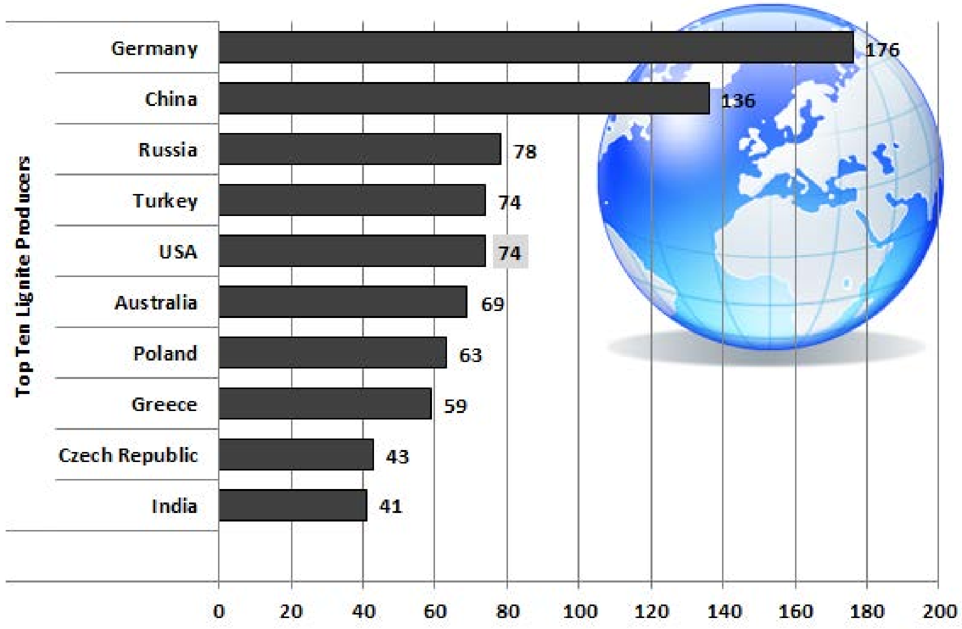

Figure 2 *Top ten lignite producers (in million tonnes) according to [W-1]*

1.1. Sources

The major basic fuel used at most power plants is coal. Coal resources are actually available in almost every country worldwide. Coal provides 30.3% of global primary energy needs. Coal generates 42% of the world‘s electricity. In 2011 coal was the fastest growing form of energy outside renewables [W-1]. The top ten coal and lignite producers along with their coal production quantities in 2011 are displayed in **Figures 1 and 2**.

As already mentioned above, coal is the major fuel used for generating electricity worldwide. Many countries rely virtually fully on coal as an energy source. In other countries coal represents a significant proportion besides other sources such as nuclear energy. **Table 1** shows the percentages of coal used for electricity generation:

According to a report from the International Energy Agency [F-1] the globally installed coal-fired power plant fleet consists of approximately 1,627GW generating capacity in total (2010). Over the last five years, net power generating capacity increased from coal-fired power plants, in particular for large power plants above 300MW capacity. More than 20% of the currently installed facilities worldwide is younger than five years old, and more than 50% of the installed facilities is younger than 20 years old. Ten countries represent more than 85% of the world’s total CO_2 emissions from coal or peat through the production of electricity and heat. The amount of coal-fired power plants as well as the total capacities are displayed in **Figure 3**.

Pulverised coal and cyclone boilers in general produce fly ash, bottom ash, and slag. A considerable quantity of fly ash is entrained in the boiler flue gas and then collected in electrostatic precipitators or baghouses. Bottom ash is formed when ash particles soften or melt and stick on the furnace walls and boiler tubes, ag-

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Country	Percentage
South Africa	93
Poland	90
PR China	79
Australia	76
Kazakhstan	70
India	69
Israel	63
Czech Republic	56
Morocco	55
Greece	55
USA	45
Germany	44

Table 1 *Coal in electricity generation (Source: [W-1])*

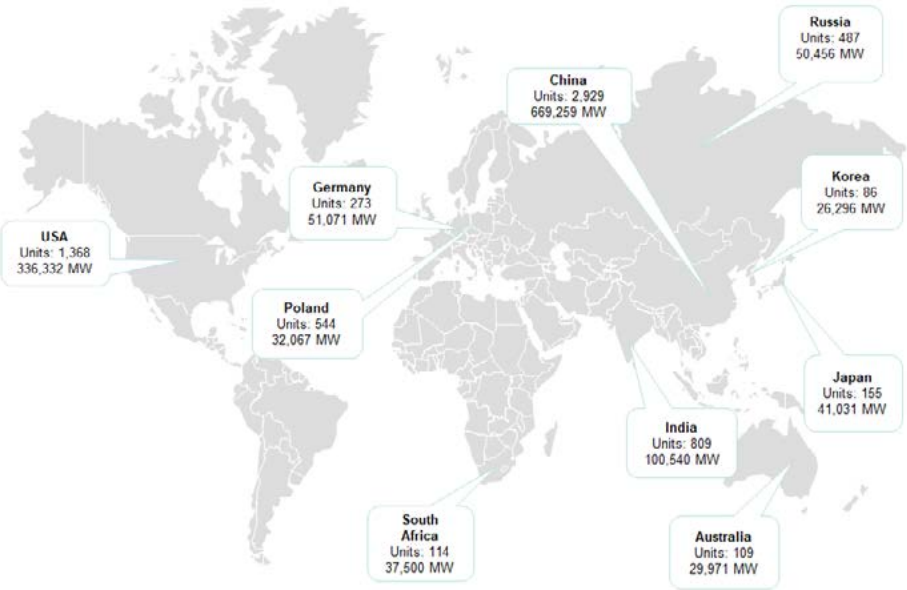

Figure 3 *Coal-fired power plants, units and capacities, according to [F-1]*

glomerating and falling into hoppers situated at the base of the furnace. The yield ratio of fly ash to bottom ash depends on the used boiler type. In dry-bottom boilers, fly ash accounts for the main ash component (80 – 90%), bottom ash is in the range of 10 – 20%. Wet-bottom boilers yield molten ash, or slag, from the furnace bottom. When such slag is removed from the boiler in a molten state, it is dropped into a water-filled ash hopper. In cyclone boilers, the slag yield accounts for a greater percentage of the total ash (70 – 85%). The relation of slag to fly ash in other wet-bottom boilers is about the same as that of bottom ash to fly ash in dry-bottom units (10 – 20% slag and 80 – 90% fly ash). Some bottom ash is transported to storage in dry form. But the majority is transported as slurry to dewatering bins or ponds, where water is removed prior to the ashes' further transfer to utilisation sites or storage stockpiles. [N-1]

1.2. Quantity and availability

In 2007 China had the largest coal ash production followed by India and Europe. By that time, the total production of coal ashes attained an estimated 620 million tonnes [B-2].

This is divided into:

- China: estimated production of 300 million tonnes
- North America: 95 million tonnes
- India: 105 million tonnes
- Europe: around 111 million tonnes
- Russia: 25 million tonnes
- South Africa: 31 million tonnes
- Japan: 11 million tonnes
- Other countries: about 42 million tonnes [B-2]

Owing to the constant need for electricity power plants normally work around the clock. Downtime phases occur a couple of weeks per year owing to maintenance of boilers, turbines and other facilities. By and large the wet ashes are available continuously over the whole year.

1.3. AFR composition

The compositions of ashes depend on the fuels, the combustion technique and the combustion process control. Thus, the ash composition varies over a wide range. **Tables 2 - 5** provide examples of different kinds of ashes.

Fly ashes are classified as Class C or Class F according to ASTM C 618 [A-1]. Class C fly ash, also referred to as high-calcium fly ash, is normally produced by burning lignite or sub-bituminous coal. Class F fly ash, also referred to as low-calcium fly ash, is generally produced by burning anthracite or bituminous coal.

Class C fly ash usually has cementitious properties in addition to pozzolanic properties which can be traced back to free lime. Class F fly ash is rarely cementitious when mixed with water alone.

1.4. Collection and transport

Normally, ashes are stored in silos at power plants, but also storage in open piles is to be found.

Ashes are transported in enclosed containers or semi-trailer lorries or by rail.

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Parameter	Unit	Boiler slag (wet ashes) from Eastern German lignite power plants (a) Range	Boiler slag (wet ashes) from Eastern German hard coal power plant (a) Average	Boiler slag German power plants (b) Range
Moisture	%	22 – 29	28.5	
SiO_2	% dm	66.8 – 74.2	49.4	40 – 55
Al_2O_3	% dm	0.9 – 8.2	21.5	23 – 35
Fe_2O_3	% dm	7.5 – 8.0	12.4	4 – 17
CaO	% dm	5.2 – 6.0	5.6	1 – 8
MgO	% dm	2.0 – 4.3	4.3	0.8 – 4.8
SO_3	% dm	0.85 – 1.3	0.51	< 0.5
Na_2O	% dm	0.1 – 0.12	0.84	0.1 – 3.5
K_2O	% dm	0.24 – 0.76	1.9	1.5 – 5.5
P_2O_5	% dm	0.04 – 0.05	0.21	
Cr	% dm	0.02 – 0.023	0.027	
Cd	ppm dm		< 2.2	
Hg	ppm dm		< 0.8	
Tl	ppm dm		< 3.2	
As	ppm dm		< 6.2	
Co	ppm dm		< 13	
Ni	ppm dm		< 79	
Pb	ppm dm		< 36	
Cr	ppm dm		< 114	
Cu	ppm dm		< 98	
Sb	ppm dm		< 22	
Be	ppm dm		< 24	
Mn	ppm dm		< 938	
Se	ppm dm		< 2.5	
Te	ppm dm		< 2.8	
V	ppm dm		< 199	
Zn	ppm dm		< 150	
Sn	ppm dm		< 2.5	

Table 2 *Chemical analyses of wet ashes and boiler slag (Sources: (a) MVW, (b) [B-1])*

Parameter	Unit	Coal bitu-minous	Coal sub-bitu-minous
SiO_2	%	61	46.8
Al_2O_3	%	25.4	18.8
Fe_2O_3	%	6.6	5.9
CaO	%	1.5	17.8
MgO	%	1	4
Na_2O	%	0.9	1.3
K_2O	%	0.2	0.3

Table 3 *Chemical composition of typical bottom ash (Source: [N-1])*

Parameter	Unit	Coal bitu-minous	Coal sub-bitu-minous
SiO_2	%	48.9	40.5
Al_2O_3	%	21.9	13.8
Fe_2O_3	%	14.3	14.2
CaO	%	1.4	22.4
MgO	%	5.2	5.6
Na_2O	%	0.7	1.7
K_2O	%	0.1	1.1

Table 4 *Chemical composition of typical boiler slag (Source: [N-1])*

Parameter	Unit	Class F fly ash		Class C fly ash	
		Typical	ASTM C-618 requirements	Typical	ASTM C-618 requirements
SiO_2	%	53.6		40.9	
Al_2O_3	%	26.3		21.6	
Fe_2O_3	%	5.2		5.5	
$SiO_2+Al_2O_3+Fe_2O_3$	%	90.2	> 70	67.7	> 50
CaO	%	4.1		19.1	
MgO	%	1.5		3.9	
SO_3	%	0.9	< 5.0	1.4	< 5.0
LOI	%	6	6	6	6
Moisture	%	0.2	< 3.0	0	< 3.0
Insoluble residue	%	0		0	
Na_2O equivalent	%	2		1.6	

Table 5 *Chemical composition of fly ashes and requirements for cement usage (Source: [N-1])*

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Coal ashes are used in a wide range of applications in the building and construction industry. In most cases the materials are used as a replacement for naturally occurring resources and therefore offer environmental benefits by not needing to quarry or mine such natural resources. Coal ashes also help to reduce energy demand as well as emissions to atmosphere as for example CO_2. Such applications include usage as an addition in concrete as cement replacement material and as an aggregate or binder in the road construction industry. They are also utilised as mineral fillers and as fertilisers. [E-2]

Figure 4 shows the utilisation of fly ash in the construction industry and in underground mining in 2008 in the EU.

Further uses of coal ashes cover several minor applications, for instance agriculture or snow and ice control. For example, in the USA the utilisation of coal ashes in 2010 is displayed in **Table 6**.

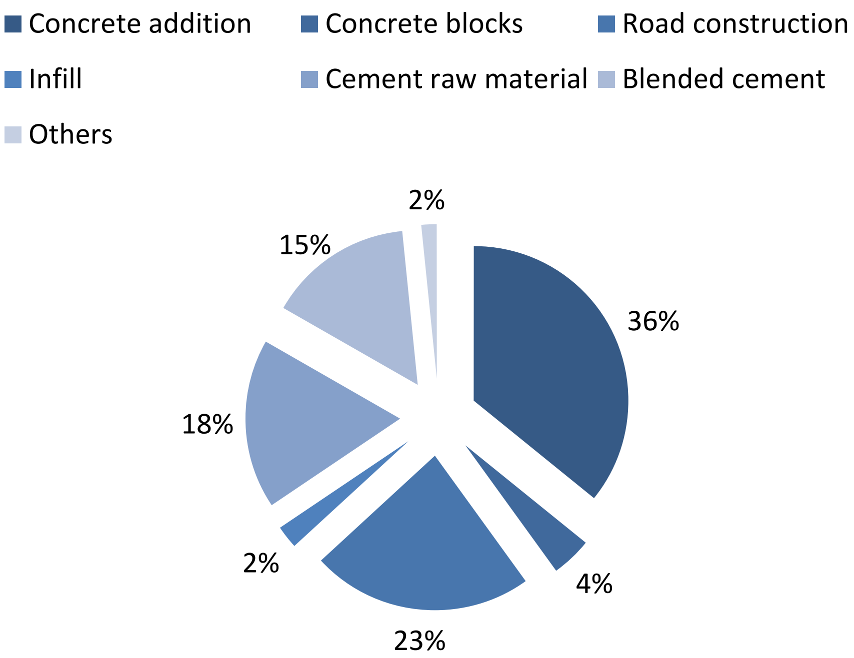

Figure 4 *Utilisation of fly ash in the construction industry and in underground mining in 2008 according to [E-2]*

Picture 5 *Fly ash loading facility for lorries in a lignite-fired power plant (source: MVW)*

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1.5. Use as alternative raw material in cement plants

Clinker

Fly ash from coal-fired power plants can be used effectively as a component of raw kiln feed for the manufacture of cement clinker. Fly ash contains significant amounts of Al_2O_3 and SiO_2, and has thus been used as a partial replacement of natural raw materials like clay and/or shale in the raw kiln feed. In some cases, however, the Fe_2O_3 content of the fly ash has also provided iron balance in the raw feed. Hence, natural iron ore can be saved.

Fly ash is used in both dry and wet processes of cement manufacture. In the dry process the fly ash has either been premixed with the raw kiln feed or introduced directly into the burning zone. The resulting clinkers have shown sufficient homogeneity although some inhomogeneities in the clinker phases have been observed when the fly ash is introduced directly into the burning zone. In the wet process, the fly ash is added to the slurry. The level of addition is dependent upon the fly ash composition and the behaviour of the slurry.

The use of high-carbon fly ash in raw kiln feed has the additional benefit of saving fuel. For instance, in a wet-process plant, a fly ash containing 15% carbon and fed at 15% raw feed replacement will save around 150kcal/kg of clinker. In a dry process plant, at a 10% replacement level, it could save nearly 10% of the total fuel energy [B-4]. However, if the carbon volatilises at a lower temperature than is used for burning, the emission of volatile organics could increase. For this reason the usage of such ashes for raw mill grinding might be restricted for suspension preheater kilns in countries which have TOC emission limits. However, if high-carbon fly ash is used for raw meal preparation in older LEPOL kilns, TOC might be not an issue.

Injecting the fly ash directly into the burning zone would prevent this problem. In a wet-process operation, high carbon fly ash can cause the segregation of carbon particles which may float on top of the slurry. The use of a Class C fly ash would result in thickening of the slurry, and may necessitate additional water or a slurry thinner to maintain the required flowability [B-4].

Owing to the large amount of silica and aluminium oxide, other ashes such as boiler ash, fluidised bed combustion ashes, bottom ashes can be used as a silica and alumina carrier for raw meal production. They partially contain carbon from incomplete combustion of coal in power plants.

Wet boiler ashes can be used, after drying, in a circulating fluidising bed reactor along with other alternative combustibles in order to produce lean gas which is used in a calciner. Once the ashes leave the circulating fluidising bed reactor they can be used without prior treatment as a raw material for raw meal production.

	Fly ash	Bottom ash	Boiler slag	Fluidised bed combustion ash
		thousand tonnes		
2010 total production	67,700	17,800	2,333	10,268
Utilisation in:				
Concrete/concrete products/grout	11,016	615.3	0	0
Blended cement/raw feed from clinker	2,046	949	3	0
Flowable fill	135	52.4	0	0
Structural fills/embarkments	4,676	3,125	78.6	0
Road base/sub-base	243	715.3	3.1	0
Soil modification/stabilisation	786	162	0	0
Snow and ice control	0	549.5	41.2	0
Blasting grit/roofing granules	86	19.9	1,258	0
Mining application	2,400	529	0	8,660
Waste stabilisation/solidification	3,259	41.2	0	71.6
Agriculture	22.2	4.7	0	0
Aggregate	6.7	555	27.2	0
Micellaneous/other	1,047	223.6	8.3	0

Table 6 *Utilisation of ashes in the U. S. in 2010 according to [A-2]*

Cement

Fly ashes are used as pozzolanic materials for cement production. The fly ashes have to fulfil certain criteria.

ASTM International [A-1] classifies fly ash into two categories—Class F and Class C.

Class C fly ash, also referred to as high-calcium fly ash, is normally produced by burning lignite or sub-bituminous coal. Class F fly ash, also referred to as low-calcium fly ash, is generally

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Parameter	Unit	Requirement
Composition: $SiO_2 + Al_2O_3 + Fe_2O_3$	%	> 70%
LOI	%	< 5.0
Cl	%	< 0.10
SO_3	%	< 3.0
Na_2O equivalent	%	< 5%
free CaO 1	%	< 1.0
Residue 45 µm	%	< 40.0
Activity index 28 days 90 days	 % %	 > 75 > 85
Soundness[1]	mm	< 10
Deviation of bulk density	kg/m³	+/- 150

[1] If free lime is higher than 1.0 %, but lower than 2.5%, soundness has to be demonstrated

Table 9 *Requirements for hard coal fly ashes according to EN 450 [E-4]*

produced by burning anthracite or bituminous coal. ASTM C 618 distinguishes Class C fly ash from Class F fly ash on the basis of the total SiO2, Al2O3, and Fe2O3 contents:

- Class F fly ash: $SiO_2 + Al_2O_3 + Fe_2O_3 >$ 70%
- Class C fly ash: 50% $< SiO_2 + Al_2O_3 + Fe_2O_3 <$ 70%

Some Class C fly ashes contain sufficient CaO themselves to be sufficiently cementitious.

The European Standard EN 197 [E-3] distinguishes between siliceous fly ashes (V) and calcareous fly ashes (W). The following requirements for fly ashes which are used for cement grinding have to be fulfilled (see **Table 7**).

Ashes V and W	LOI < 5%
Siliceous ashes (V)	< 10% reactive CaO < 1% free lime. Ashes with free lime between 1 and 2.5% can be accepted if a soundness test of a mixture 30% fly ash and 70% OPC results in < 10mm Reactive SiO_2 > 25%
Calcarious ashes (W)	Reactive CaO > 10% If reactive CaO between 10 and 15%, then reactive SiO_2 has to be > 25% If reactive CaO > 15%, the compressive strength test according to EN 196-1 after 28 days has to be > 10MPa

Table 7 *Requirements of fly ashes for cement production according to EN 197 [E-3]*

The permitted proportions of fly ashes in cements are regulated by corresponding cement standards. For instance, the European standard EN 197 [E-3] specifies the following cements containing fly ashes and their composition (see **Table 8**).

Concrete

Fly ashes find markets also in concrete manufacturing. There are strong requirements to be fulfilled when using fly ashes for concrete buildings. For instance, the European standard EN 450 Fly Ash for Concrete [E-4] describes the following provisions for fly ashes (see **Table 9**).

Table 8 *Cement compositions according to EN 197-1 [E-3]*

Main Types	Notation of cement		Composition [proportion by mass]: Main constituents: Clinker K	Blast-furnace S	Pozzolana natural P	Pozzolana natural calcined Q	Fly ash siliceous V	Fly ash calcareous W	Minor additional constituents
CEM II	Portland-fly ash cement	CEM II / A-V	80-94	–	–	–	6-20	–	0-5
		CEM II / B-V	65-79	–	–	–	21-35	–	0-5
		CEM II / A-W	80-94	–	–	–	–	6-20	0-5
		CEM II / B-W	65-79	–	–	–	–	21-35	0-5
	Portland-composite cement	CEM II / A-M	80-94	6-20					0-5
		CEM II / B-M	65-79	21-35					0-5
CEM IV	Pozzolanic cement	CEM IV / A	65-89	–	11-35				0-5
		CEM IV / B	45-64	–	36-55				0-5
CEM V	Composite cement	CEM V / A	40-64	18-30	18-30			–	0-5
		CEM V / B	20-38	31-50	31-50			–	0-5

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1.5.1. Quality influence on clinker and cement

As described above, CCP contain significant amounts of Al_2O_3 and SiO_2, sometimes also high levels of Fe_2O_3. This influences the LSF, AM and SM as well. Owing to the wide variation in chemical compositions of CCPs it is not possible to predict the influences on the modules. Each case has to be evaluated individually.

Fly ash containing cements display some special features:

- Good workability thanks to the ball-shaped fly ash
- Lower heat generation compared to ordinary portland cement OPC, therefore less cracks in solid concrete
- Comparing to OPC: Lower early compressive strength and comparable late compressive strength
- Less tendency to blooming

2. Recommendations

- The usage of CCP in clinker production can save natural resources such as clay, iron, or shale.
- For every tonne of fly ash used in replacement, one tonne of CO_2 emission is avoided. This could prove to be a significant element of an overall greenhouse gas reduction strategy.

Power plant ashes are a common waste in almost all countries in the world. As alternative raw material in the cement industry, such wastes can safe significant CO_2 emissions and reduce the environmental impact of cement production- last but not least- the use of such ashes is a good tool to reduce costs.

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