

The role of CEMENT in the 2050 LOW CARBON ECONOMY



THE EUROPEAN
CEMENT ASSOCIATION



CONTENTS

04	Foreword
08	The European cement industry in numbers
10	A low-carbon European concrete and cement sector in 2050
14	The story of cement manufacture
18	Where is cement used?
23	Where is the sector now?
26 	Five Parallel Routes
28 	Five Parallel Routes: Resource Efficiency
28	1.1 Alternative fuels
32	1.2 Raw material substitution
34	1.3 Clinker substitution
36	1.4 Novel cements
38	1.5 Transport efficiency
39 	Five Parallel Routes: Energy Efficiency
39	2.1 Electrical energy efficiency
41	2.2 Thermal energy efficiency
43 	Five Parallel Routes: Carbon sequestration and reuse
43	3.1 Carbon sequestration and reuse
47	3.2 Biological carbon capture
48 	Five Parallel Routes: Product Efficiency
48	4.1 Low carbon concrete
50 	Five Parallel Routes: Downstream
50	Why is concrete used?
52	5.1 Smart building and infrastructure development
54	5.2 Recycling concrete
55	5.3 Recarbonation
56	5.4 Sustainable construction
58	Towards the future
61	Annex 1: European standards for cement and concrete
62	Annex 2: Sustainable cement production



FOREWORD

by the President, Peter Hoddinott



Mr Peter Hoddinott
President of CEMBUREAU

Concrete Action for 2050

Mankind's invention of concrete has been a key event in evolution. Its simplicity, durability, strength, affordability and infinite ability to be moulded provide the solid foundations and essential built environment for society. Some call it 'liquid stone' allowing architects, community planners and homebuilders to realise their dreams, including the creation of spaces of beauty and light. But it goes beyond that. Concrete works equally well underwater, underground, in Arctic conditions and on the top floors of skyscrapers. It has high fire resistance. It absorbs and releases heat, acting as a natural air conditioner due to this 'thermal inertia'. The result of all this is that concrete is the third most used substance in the world after air and water, a staple of modern life and society.

This document will focus on what can be done to reduce CO₂ in cement production using today's technology, and will speculate on what could be achieved by 2050.

Of course, there is a catch. The special ingredient or glue which makes all this possible is a rather ordinary-looking grey powder called cement, the production of which typically produces 600-700kg of CO₂ per tonne. This is because it needs energy (both fuel and electricity) and the production process releases CO₂. Globally, cement production accounts for around 5% of man-made CO₂ emissions. The industry recognises this responsibility and embraces its commitment to reduce this markedly, especially by contributing to the circular economy. This document will focus on what can be done to reduce CO₂ in cement production using today's technology, and will speculate on what could be achieved by 2050.



Depending on design, concrete buildings and structures can be supremely elegant. The same goes for energy efficiency, where concrete has a major role to play. Its thermal inertia means that intelligently-conceived modern concrete buildings can use 75% less energy over their whole life cycle.

But there is a secondary responsibility for the industry. For example, around 18% of global energy (with resultant CO₂) is consumed by conventional buildings during their life – and this figure rises to over 35% in Europe. Depending on design, concrete buildings and structures can be supremely elegant. The same goes for energy efficiency, where concrete has a major role to play. Its thermal inertia means that intelligently-conceived modern concrete buildings can use 75% less energy over their whole life cycle. Thus, how and when concrete is used can have a profound effect on global emissions. The cement industry is a leader in concrete research, development, production and technology. Through innovative application and concrete products, the contribution of the industry to the low carbon economy of 2050 can and will go beyond reductions in emissions from cement production.

Predicting the future is a notoriously hazardous activity. What is certain is that the world in 2050 will be a very different place from today. Just look at how people 40 years ago imagined the world in the 2010s to be. Few predicted that China would be on its way to overtaking the US as the world's largest

economy, nor foresaw the shale gas revolution nor the importance of Moore's Law. Today, we have access to virtually all global knowledge using a device that fits in our pocket, even though its most popular use is to share one's life with 500+ friends. Nevertheless, there are a few distinct trends:

- Between 2011 and 2050, the world population is expected to increase from 7.0 billion to 9.3 billion.¹
- At the same time, the urban population will increase from 3.6 billion in 2011 to probably over 6 billion in 2050.
- A world economy four times larger than today's is projected to require 80% more energy.
- The volume of travel within urban areas is anticipated to triple by 2050, with the number of cars worldwide doubling to more than 2 billion.
- Innovation in construction will make buildings more energy efficient and could turn them from energy consumers into energy producers.

¹ Source: United Nations, 2011

This increase in population and economic growth will place added strain on already limited resources, and will require sustained efforts to mitigate the effects of climate change. Cement, as a key component of concrete, will have a very important role to play in managing resources and providing solutions to deal with increased population and urbanisation, with possible levers including:

- Innovative buildings to provide energy-efficient housing solutions or work spaces that will double as platforms to generate renewable energy.
- New transport solutions to minimise their environmental effects and congestion.
- Vertical buildings to reduce space needed to house 9 billion people.
- Large-scale projects to help capture the power of wind, tides and the sun.
- Infrastructure to help protect us from a possible rise in sea levels.

Concrete will be the main material of choice for most of these solutions. As an industry, however, we will not focus only on the solutions we provide, but also continue to act responsibly to manufacture with maximum care. This roadmap explores different routes and possibilities for achieving a substantial reduction in CO₂ emissions in cement production. Moreover, their impact will not be limited to reducing CO₂ emissions, but can also lead to a meaningful decrease in other greenhouse gas emissions, as well as energy and use of natural resources. We are confident that a combination of parallel routes will result in a sustainable cement industry in Europe.

It is important to remember that the cement industry does not stand alone; it is part of the European construction sector. In this context, it is useful to look beyond the factory gate and see how innovation in concrete and building techniques can contribute to more sustainable construction and buildings.

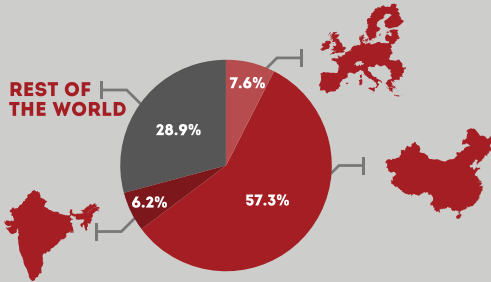
We look forward to working with the construction sector, policy makers, research communities and civil society in the course of this journey. We hope this document will inspire a dialogue that will result in an increasingly sustainable European cement and concrete industry for the world we live in today and will share tomorrow.



We are confident that a combination of parallel routes will result in a sustainable cement industry in Europe.

The European CEMENT INDUSTRY IN NUMBERS

IN 2011, EUROPE ACCOUNTED FOR 7.6% OF TOTAL **GLOBAL CEMENT PRODUCTION**. CHINA WAS RESPONSIBLE FOR 57.3% AND INDIA FOR 6.2%

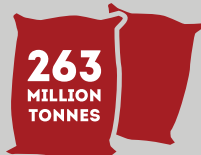


EUROPE USES BY FAR THE HIGHEST QUANTITY OF ALTERNATIVE FUELS IN CEMENT PRODUCTION:

8.7% OF THESE FUELS ORIGINATED FROM BIOMASS WASTE AND **25.6%** FROM OTHER WASTE IN 2011. FURTHERMORE, THE AMOUNTS ARE STEADILY INCREASING



IN 2011, **CEMENT PRODUCTION** IN THE EU27 PLUS TURKEY AMOUNTED TO



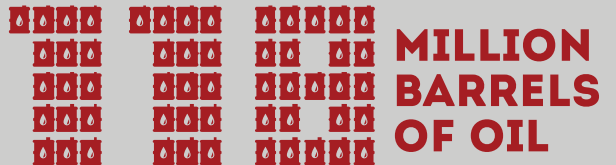
WITH A **PRODUCTION VALUE OF**



EUROPEAN COMPANIES FILED OVER CEMENT RELATED **800** PATENTS IN 2011



EU27 THERMAL ENERGY CONSUMPTION FOR CEMENT PRODUCTION IN 2010 WAS **7.6 X 10¹¹ MJ**, OR THE ENERGY EQUIVALENT OF APPROXIMATELY



WITH A **PRODUCTION VALUE OF**



IN 2010, ABSOLUTE EUROPEAN CO₂ EMISSIONS WERE 40 MILLION TONNES LOWER THAN IN 1990, OR THE EQUIVALENT, PER PASSENGER, OF 29 MILLION RETURN FLIGHTS BETWEEN BRUSSELS AND NEW YORK

[1] The cement sector: a strategic contributor to Europe's future – Boston Consulting Group, 2013 <http://www.cembureau.eu/sites/default/files/documents/The%20Cement%20Sector%20-%20A%20Strategic%20Contributor%20to%20Europe%27s%20Future.pdf>

[2] Based on http://www.carbonindependent.org/sources_aviation.htm



3 OF THE WORLD'S FIVE LARGEST GLOBAL CEMENT PRODUCERS ARE HEADQUARTERED IN THE EU28

88-98% OF A BUILDING'S TOTAL LIFE CYCLE EMISSIONS ARE LINKED TO THE USE PHASE

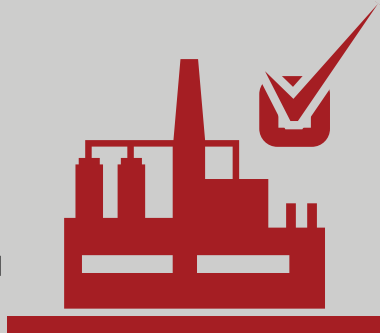


CONTINUED RESEARCH HAS LED TO A SUBSTANTIAL INCREASE IN THE COMPRESSIVE STRENGTH OF CONCRETE, MEANING **LESS CONCRETE** IS NEEDED FOR THE SAME JOB



OVER **90%**

OF ALL CEMENT PLANTS IN EUROPE ARE EQUIPPED WITH **ENERGY-EFFICIENT DRY KILNS**

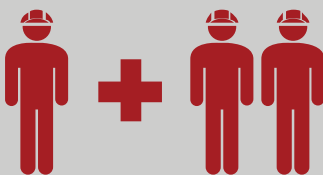


THE EUROPEAN CEMENT INDUSTRY GENERATES APPROXIMATELY

[3]



366,000 DIRECT AND INDIRECT JOBS



FOR EVERY NEW JOB IN CONSTRUCTION, TWO ADDITIONAL JOBS ARE CREATED ELSEWHERE IN THE ECONOMY

[4]

IN 2011, THE EUROPEAN CEMENT INDUSTRY USED OVER

7 MILLION TONNES

OF ALTERNATIVE FUELS, A 6-FOLD INCREASE COMPARED TO 1990, SAVING THE EQUIVALENT OF

17 MILLION TONNES OF CO₂

[3] Cement and concrete for EU 27 and Turkey. Source Eurostat and CEMBUREAU

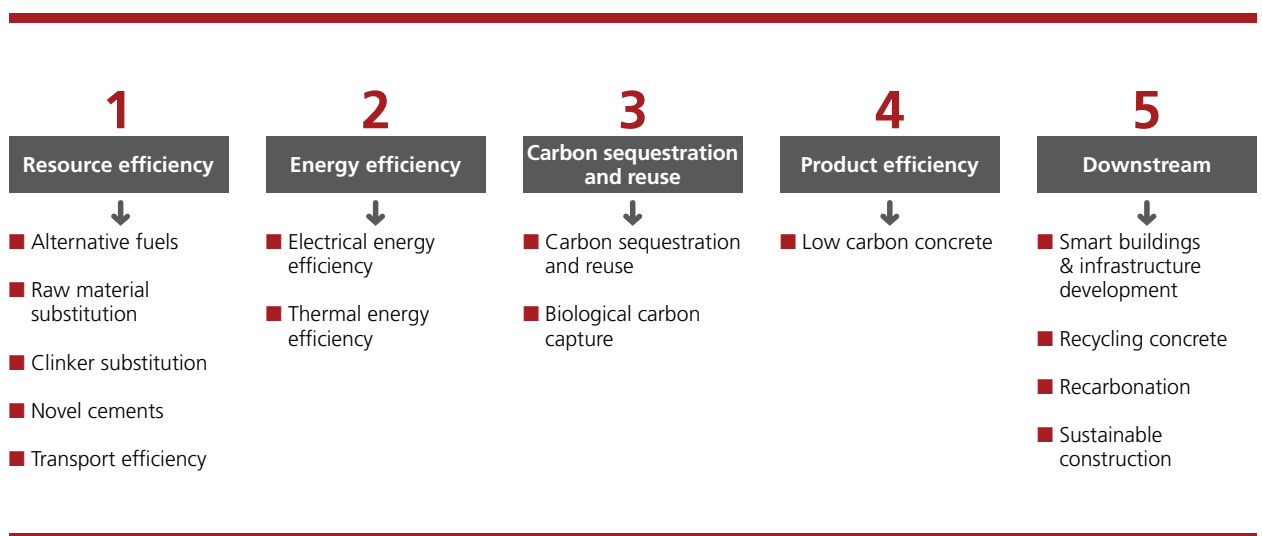
[4] Communication from the European Commission "The Competitiveness of the Construction Industry" COM(97) 539 of 4/11/97

A low-carbon European concrete and cement sector in 2050

This document presents a vision for the sector whereby the cement carbon footprint could be reduced by 32% compared with 1990 levels, using mostly conventional means. It also describes potential levers for how this could be further increased by the application of emerging new technologies, such as carbon capture and storage (CCS). Subject to specified policies and technological prerequisites, a potential reduction of up to 80% may be envisaged.

The industry has focused on five routes to achieve these objectives, three of which are considered to be 'under the sector's control'. Potential savings from the other two routes outlined (Product Efficiency and Downstream) do not relate directly to cement manufacturing, so were not included. The sector is

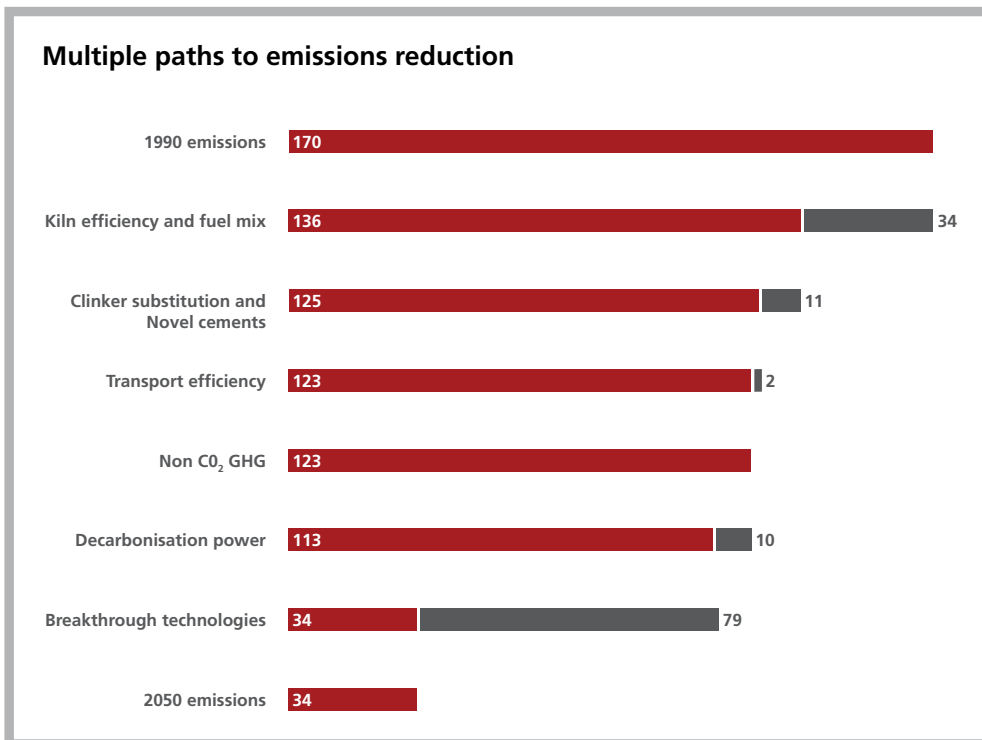
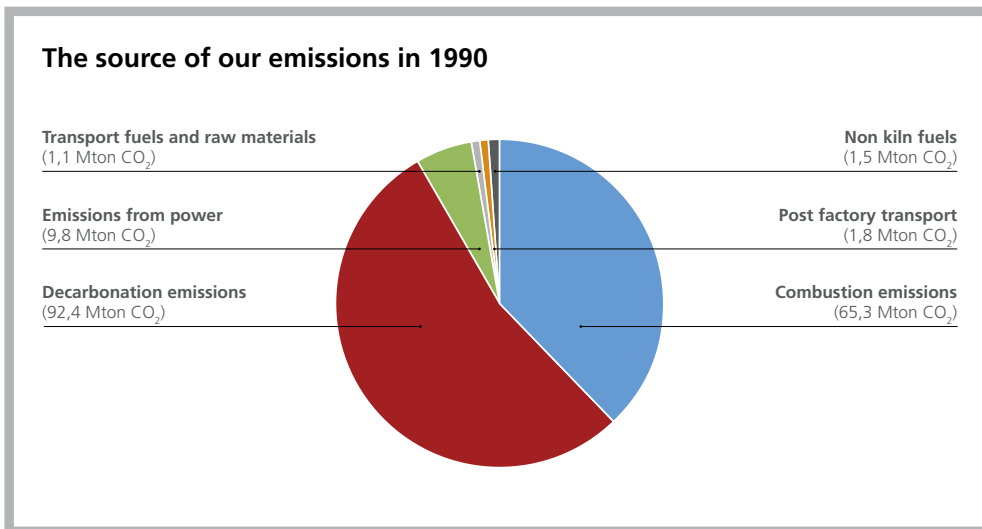
committed, however, to investing in innovation that explores new ways for cement and concrete to contribute to a low carbon and circular economy, especially where life cycle emissions of buildings and structures can be meaningfully reduced by intelligent use of concrete. This could increase the overall contribution further.



For each lever, the roadmap lays out the key success factors, challenges and policy recommendations.

There is no single choice or technology that will lead to an 80% reduction in emissions. Only a combination of different ways to reduce emissions, as set out in each of the chapters below, can

achieve substantial reductions. The contribution of each of the levers to the overall reduction is summarised in the graphs below.





Use of alternative fuels has steadily increased over the past decades and this increase is set to continue. We based our calculations on a fuel mix composed of 60% alternative fuels (40% of which would be biomass), 30% coal and 10% petcoke.

Building blocks and assumptions

In order to calculate potential savings, we made a series of assumptions on:

Production volume

We do not know how much cement will be produced in Europe by 2050. For the numbers to be meaningful, we assumed that the same amount of cement will be manufactured in 2050 as in 1990.

Power generation

Although electricity is far from being the largest contributor to our emissions, we do use electrical power in the production process. Installing carbon capture will substantially increase our power consumption. In our calculation, we assumed the power sector to have been fully decarbonised by 2050.

Transport emissions

Innovation and standards in the transport sector will further reduce emissions related to transporting raw materials to the plant, so a 50% increase in the efficiency of all modes of transport has been assumed. The reduction in post-cement plant

transport emissions has been based on estimates included in the UK Department of Energy & Climate Change's 2050 pathway, namely that the share of road transportation will be 50%, rail 23% and water 23%.

Plant capacity

The size of a cement plant has an impact on emissions and larger plants tend to be more efficient. We assume that plants will be further consolidated and that average production capacity will double to 5000 tonnes of clinker per day.

Fuel mix

Use of alternative fuels has steadily increased over the past decades and this increase is set to continue. We based our calculations on a fuel mix composed of 60% alternative fuels (40% of which would be biomass), 30% coal and 10% petcoke. Nevertheless, given the increase in the use of alternative fuels, it has been assumed that there will not be any further improvements in energy consumption from fossil fuels. For non-kiln fuels, which includes the drying of raw materials, vehicles used on site and space heating, a 30% reduction in emissions has been forecast.



Clinker content and novel cements

It has been assumed that cement manufactured in 2050 will contain an average of 70% clinker. In addition, novel cements (CO₂ emissions from which are estimated to be 50% lower than from common cements) could make up 5% of total cement production.

Breakthrough technologies

On the basis of the above assumptions, it has been estimated that a 32% reduction in CO₂ emissions could potentially be achieved by the cement industry. Hence, in order for the sector to reach the 80% reduction suggested by the European Commission, breakthrough technologies are needed. According to the calculations, 81Mt of CO₂ will still need to be eliminated. It has therefore been assumed that 85% of total clinker production (equivalent to 59% of cement plants) will need to be equipped with, for example, carbon capture and storage technology.

In order for the sector to reach the 80% reduction suggested by the European Commission, breakthrough technologies are needed. According to the calculations, 81Mt of CO₂ will still need to be eliminated. It has therefore been assumed that 85% of total clinker production (equivalent to 59% of cement plants) will need to be equipped with, for example, carbon capture and storage technology.

The story of CEMENT MANUFACTURE

Before entering into the detail of each of the five parallel routes, it is essential to provide more background on the industrial context in which these reductions are suggested. In the chapters below, more information is provided on the characteristics of cement, its production process and use and where the sector is now in terms of emission reductions already achieved.



The cement used by the Romans was produced using locally available raw materials, chalk and volcanic ash heated in open fires.

What is cement?

Cement is a fine, soft, powdery-type substance, mainly used to bind fine sand and coarse aggregates together in concrete. Cement is a glue, acting as a hydraulic binder, i.e. it hardens when water is added.

Everyone knows the word cement, but it is often confused with concrete or mortar. Cement is a key ingredient in both concrete and mortar, and it is always mixed with other materials before use:

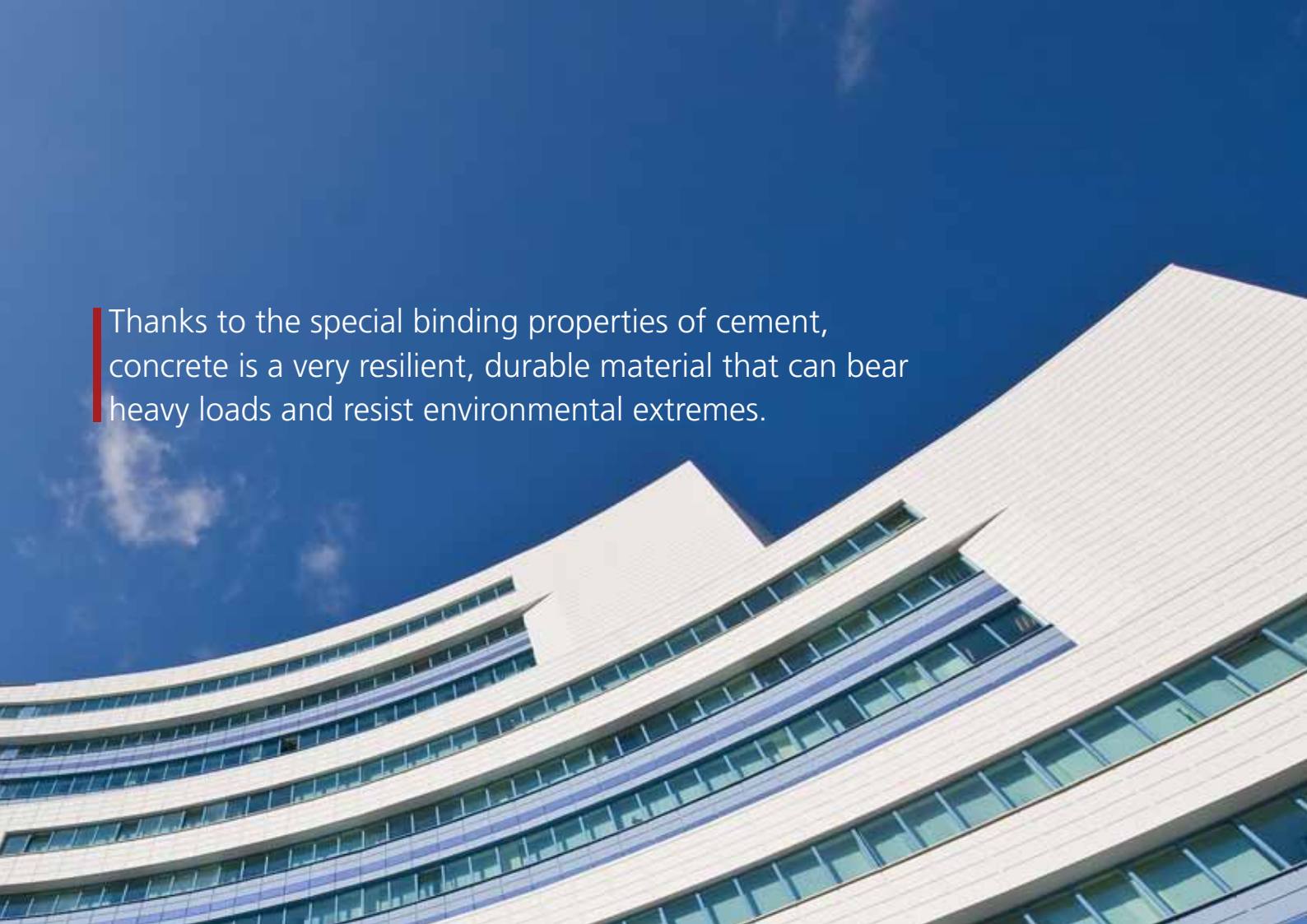
- Cement mixed with water, sand and gravel forms concrete, which is what the vast majority of cement is used for.
- Cement mixed with water, lime and sand forms mortar.

Cement and concrete have been used to build durable structures for quite some time.

The Coliseum in Rome, completed in 80 AD, is a good example of how a concrete structure can withstand time. The cement used by the Romans was produced using locally available raw materials, chalk and volcanic ash heated in open fires.

The modern version of cement, called Portland cement, was developed back in the early 19th century and has been improved ever since.

There are 27 types of common cements that can be grouped into five general categories (CEM I Portland cement, CEM II Portland-composite cement, CEM III Blastfurnace cement, CEM IV Pozzolanic cement, and CEM V Composite cement) and three strength classes: ordinary, high and very high. The standard for common cements further specifies 7 sulfate resisting common cements, 3 distinct low early-strength blast furnace cements and 2 sulfate resisting low early strength blast furnace cements. There are also a number of special



Thanks to the special binding properties of cement, concrete is a very resilient, durable material that can bear heavy loads and resist environmental extremes.

cements, such as super sulfate-cement, very low-heat cement and calcium aluminate cement.

What is concrete?

Concrete is a mixture of cement, water, aggregates and, in some cases, small quantities of chemical admixtures. Aggregates make up approximately 60-75% of the mixture and cement and water make up the rest. Aggregates are usually inert coarse materials like gravel, crushed stone, sand or recycled concrete. The types of aggregate and cement selected depend on the application of the concrete. Thanks to the special binding properties of cement, concrete is a very resilient, durable material that can bear heavy loads and resist environmental extremes.

Cement & concrete

The vast majority of cement is used to make concrete. For this reason, any roadmap must also take into account the final product, i.e. concrete. This is especially relevant because as more new cement types are developed, the amount of cement needed to make concrete could vary.

An efficient use of cement products and concrete and the end-of-life aspects of these products have

a direct impact on the sustainability of concrete. This roadmap will therefore also look into innovative construction methods that will allow reuse of concrete building elements and components.

Cement manufacture

The cement-making process can be divided into two basic steps:

- Clinker (the main constituent of cement) is first made in a kiln with gas up to 2000°C, which heats raw materials such as limestone (calcium carbonate) with small quantities of other materials (e.g. clay) to 1,450°C. During this process, known as calcination, the calcium carbonate (limestone) is transformed into calcium oxide (lime), which then reacts with the other constituents from the raw material to form new minerals, collectively called clinker. This near-molten material is rapidly cooled to a temperature of 100 - 200°C.
- Clinker is then ground with gypsum and other materials to produce the grey powder known as cement.

An efficient use of cement products and concrete and the end-of-life aspects of these products have a direct impact on the sustainability of concrete. This roadmap will therefore also look into innovative construction methods that will allow reuse of concrete building elements and components.



1 - Clinker production

■ *Quarrying raw materials*

Cement plants are typically located close to naturally occurring materials like limestone, marl or chalk, which are extracted from quarries, providing calcium carbonate (CaCO_3). Very small amounts of materials such as iron ore, bauxite, shale, clay or sand may be needed to provide the extra mineral ingredients, iron oxide (Fe_2O_3), alumina (Al_2O_3) and silica (SiO_2) necessary to produce the desired clinker.

■ *Crushing*

Raw material is quarried and transported to primary/secondary crushers and broken into 10cm pieces.

■ *Raw meal grinding*

After crushing, the raw materials are mixed and milled together to produce 'raw meal'. To ensure high cement quality, the chemistry of the raw materials and the subsequent raw meal is very carefully monitored and controlled.

■ *Preheating*

Hot exhaust gases coming from the kiln preheat the powdered raw meal before it enters the kiln. A preheater consists of a series of cyclones through which the raw meal is passed by swirling hot flue gases in the opposite direction of the material flow. In these cyclones, thermal energy (heat) is recovered from hot flue gases with the benefits that the raw meal is preheated, the efficiency of the process is improved and less fuel is needed. Depending on the raw material moisture content and heat recovery requirements, a kiln may have up to six stages of cyclones, with increasing heat recovery at each extra stage.

■ *Precalcining*

Calcination is the transformation of limestone into lime. Part of the high temperature reaction in modern installations takes place in a 'precalciner', a combustion chamber at the bottom of the preheater above the kiln, and partly in the kiln. Here, the chemical decomposition of limestone, generating typically 60% of total CO_2 emissions of the cement manufacturing process occurs. Fuel combustion generates the rest of the CO_2 .



■ *Clinker production in the rotary kiln*

Precalcined meal then enters the kiln at temperatures of around 1000°C. Fuel (such as coal, petroleum coke, gas, oil and alternative fuels) is fired directly into the rotary kiln at up to 2000°C to ensure that the raw materials reach material temperatures of up to 1,450°C. The kiln (a brick-lined metal tube 3-5 metres wide and 30-60 metres long) rotates about 3-5 times per minute, and the raw material flows down through progressively hotter zones of the kiln towards the flame. The intense heat causes chemical and physical reactions that partially melt the meal into clinker. There are older, much less efficient technologies, for example wet kilns into which raw material is fed as wet slurry and not as powder (as is the case in dry kilns). However, wet kilns have almost been phased out and today over 90% of European cement clinker is produced in dry kilns.



■ *Cooling and storing*

From the kiln, the hot clinker is cooled using large quantities of air, part of which can serve as combustion air. Coolers are essential for the creation of the clinker minerals which define the performance of the cement. In this process, the combustion air is preheated, thereby minimising overall energy loss from the system. Clinker is usually used on site but can be transported by truck, train or ship to other grinding plants.



2 - Cement grinding

Around 4-5% gypsum is added to clinker to control the setting time of the final cement. The cooled clinker and gypsum mixture is ground into a grey powder called Ordinary Portland Cement (OPC), or can be ground with other mineral components to produce, for example, Portland Composite Cements (PCC). Traditionally, ball mills have been used for grinding, although more efficient technologies like roller presses and vertical mills or combinations thereof are used in many modern plants today.



■ *Blending*

Cement may also be mixed with other finely ground mineral components, such as considerable amounts of slag, fly ash, limestone or other materials to replace part of the clinker, thereby often achieving a significant reduction of the CO₂ emissions.



■ *Storing in cement silos*

The final product is homogenised and stored in cement silos and then dispatched to either a packing station (for bagged cement) or to a silo for transport by water, road or rail.

Where is CEMENT USED?

Cement plays a key, but often unnoticed, role in our lives. Cement is mainly used as a binder in concrete, which is a basic material for all types of construction, including housing, roads, schools, hospitals, dams and ports, as well as for decorative applications (for patios, floors, staircases, driveways, pool decks) and items like tables, sculptures or bookcases. Concrete is a versatile and reliable construction material with a wide range of applications. When looking at possible pathways to reduce the carbon footprint of the European cement industry, it is important to examine some of the characteristics of the industry that will influence the availability or viability of emission reduction options.

Why does the present roadmap focus on CO₂?

The cement industry is CO₂-, energy- and material-intensive. Measures to decrease energy consumption and to improve resource efficiency will, de facto, reduce CO₂ emissions (hence the focus on CO₂ emissions). The combination of process emissions (emissions released when limestone is transformed into lime during the production process) and emissions from the required thermal energy leads to substantial CO₂ emissions for each tonne of cement. It should be noted that the generation of other greenhouse gases like CH₄ and N₂O occurs in only insignificant quantities in the cement manufacturing process⁶.

A process and capital intensive industry

The cost of constructing a new cement plant with 1 million tonnes of annual capacity is typically more than €150 million. Modernisation of existing cement plants is also very expensive. In addition, and in order to meet European environmental legislation, operations face major investments and operating costs. 30% of the cement industry's total operating expenses relate to energy costs. The cost of a new cement plant is equivalent to

around three years of turnover, which ranks the cement industry among the most capital-intensive industries. Long periods are therefore needed before these large investments can be recovered. Plant modifications have to be carefully planned, as typical investment cycles in the sector last about 30 years. Consequently, achieving the 2050 low-carbon economy roadmap for the European cement industry will be based on balancing recent investments with planning new investments in the coming decades.

An industry with a homogeneous product

Although produced from naturally occurring raw materials that can vary widely from plant to plant, cement is a product manufactured in Europe according to a harmonised standard. Despite the existence of specialised segments, many cements are interchangeable, which promotes a competitive cement market. This also means that European production can be very vulnerable to cheaper imports.

⁶ Cement Sustainability Initiative (CSI): CO₂ and Energy Accounting and Reporting Standard for the Cement Industry, May 2011



Achieving the 2050 low-carbon economy roadmap for the European cement industry will be based on balancing recent investments with planning new investments in the coming decades.

A local industry

Cement is mostly locally produced and locally consumed. However, it is also transported over long distances by sea, river and land as plants rationalise and exploit efficiencies of scale. Land transportation costs are significant. Transporting cement costs about €10 per tonne for every 100km by road and around €15 per tonne to cross the Mediterranean Sea⁷.

In addition, transport costs per tonne are lower to ship a large consignment of cement from the north coast of France across the Atlantic than to truck it to Paris. For plants not operating at capacity, the cost per tonne to produce an additional tonne can be relatively low. With a substantial part of the European cement market within the economically viable range of a sea port, these factors together mean that European cement plants are vulnerable to imports.

An industry linked to economic cycles

Cement consumption is closely linked to economic development in the local region or country. In mature markets, such as Europe, where cement consumption per capita still varies considerably from one country to another, cement sales are dependent on activity in the construction sector, which closely follows (usually after a brief delay) general economic activity.

⁷ Source: Climate Strategies, 2007

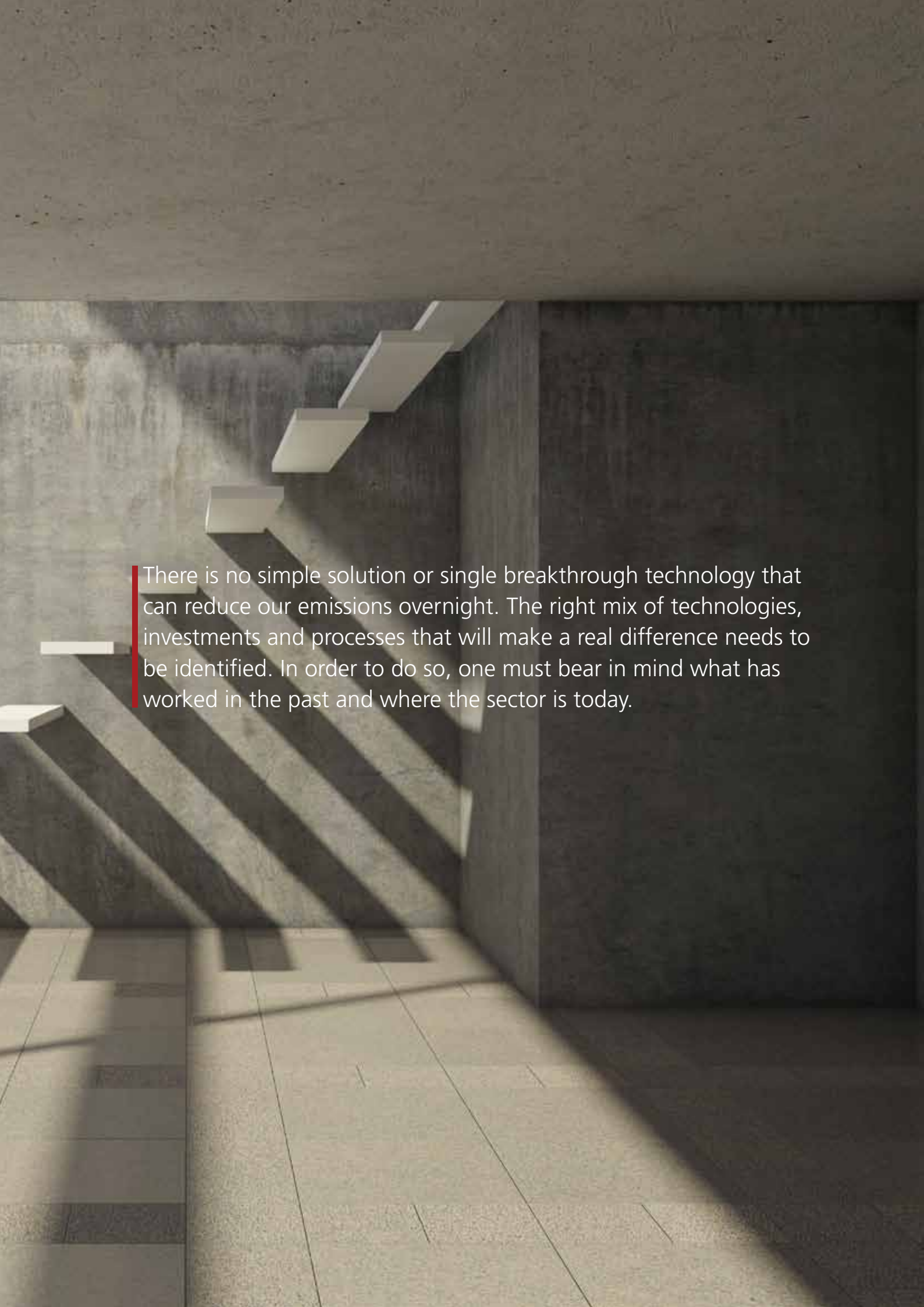
Concrete:
Simplicity, Durability, Strength,
affordability and versatility

Airports Green roofs Bridges
Elevated trains Swimming High rise office
Cargo ships Statues pools **Stairs** buildings



Water pipes
Grain silos
Tunnel
Multi storey car parks
Wind Power
Houses
Dams
Roads
Water reservoirs
Dikes
High rise residential buildings





There is no simple solution or single breakthrough technology that can reduce our emissions overnight. The right mix of technologies, investments and processes that will make a real difference needs to be identified. In order to do so, one must bear in mind what has worked in the past and where the sector is today.

Where is the SECTOR NOW?

The cement industry is CO₂-, energy- and material-intensive. Measures to decrease energy consumption and improve resource efficiency will, de facto, reduce CO₂ emissions, hence the focus on CO₂ emissions. The combination of process emissions (those released when limestone is transformed into lime during the production process) and emissions from the required thermal energy meant that typical CO₂ emissions for each tonne of clinker in 1990 were 912 kg. Reducing CO₂ emissions takes a concerted effort on many parallel routes. However, there is no simple solution or single breakthrough technology that can reduce our emissions overnight. The right mix of technologies, investments and processes that will make a real difference needs to be identified. In order to do so, one must bear in mind what has worked in the past and where the sector is today.

Reduction over the past 20 years

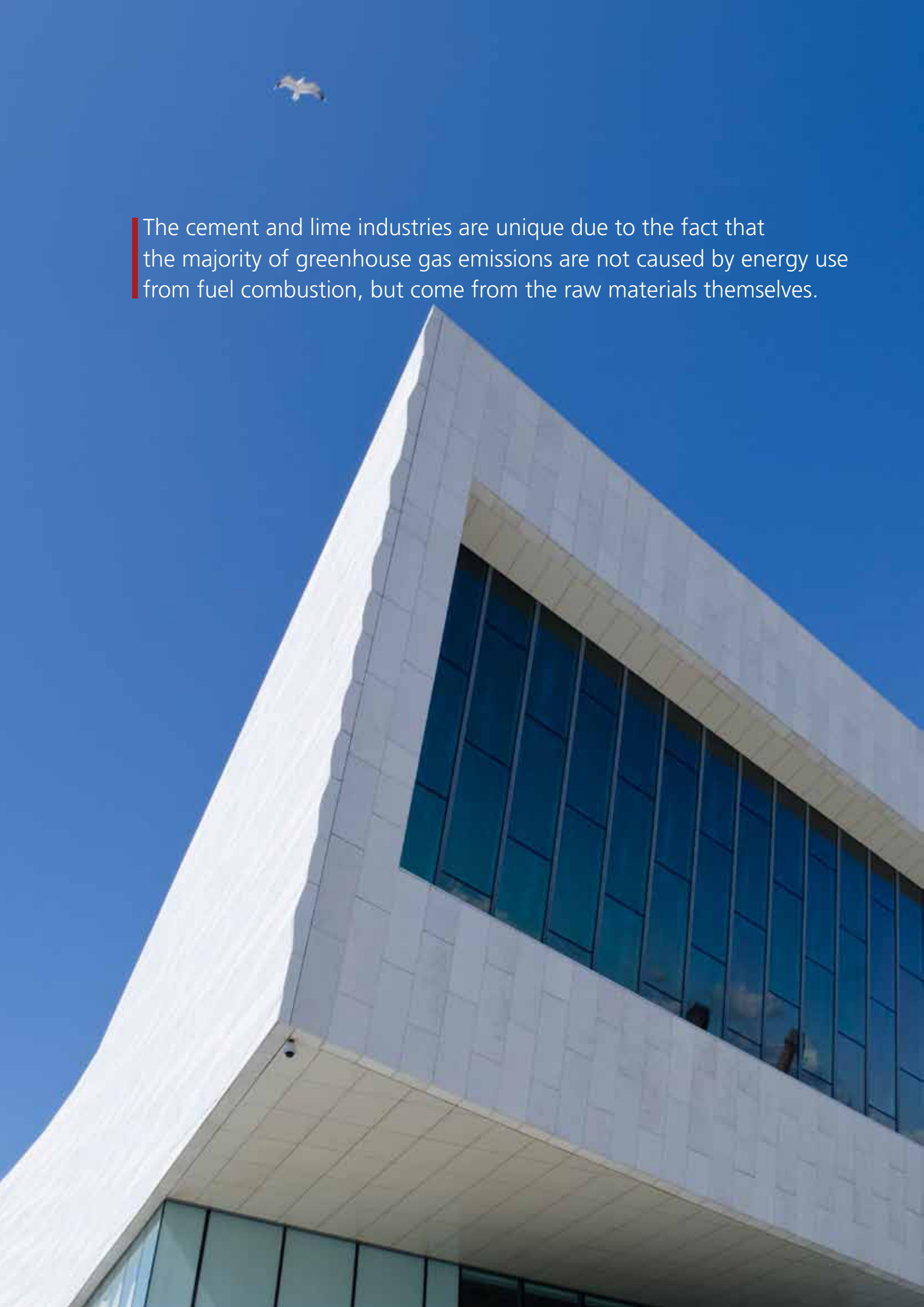
Over the past 20 years, the European cement industry has reduced CO₂ emissions per tonne of cement from 719 kg in 1990 to 660 kg in 2010 by implementing measures including:

- Replacing older wet technology kilns with far more energy-efficient dry technology kilns. Today, over 90% of the clinker produced in Europe is based on this technology.
- Improving grinding technologies, resulting in reduced power consumption and therefore reduced emissions by the power sector.
- Enhancing thermal energy consumption, leading to very high thermal energy efficiency in the clinker production process.
- Optimising and modernising existing plants by installing state-of-the-art automation, process control technology and auxiliary equipment.
- Using greater quantities of alternative fuels (a sevenfold increase since 1990), consisting of either waste material or biomass.
- Utilising waste material like contaminated soils, construction waste, ceramic moulds, foundry sand, gypsum from plasterboard, mill scale, cement kiln dust, refractory bricks and road sweepings or fly ashes as raw materials, thereby reducing the requirement for limestone and other virgin materials in the production process. This is possible due to the very high temperatures present in the kiln, destroying all incoming minerals and

turning them into completely new clinker minerals.

- Substituting clinker with materials such as finely ground limestone filler material, ground naturally occurring pozzolans or reactive by-products from other industries, such as fly ash.

The efforts to reduce our CO₂ emissions have been an integral part of improving the sustainability of our businesses and meeting the needs of our customers.



The cement and lime industries are unique due to the fact that the majority of greenhouse gas emissions are not caused by energy use from fuel combustion, but come from the raw materials themselves.



Our unique carbon profile

The cement and lime industries are unique due to the fact that the majority of greenhouse gas emissions are not caused by energy use from fuel combustion, but come from the raw materials themselves. Around 60% of total CO₂ emissions from clinker production are released directly from the processing of limestone. Of the remaining 40%, most originate from burning fuel in the kiln to reach the high temperatures necessary for clinker mineral

formation. Indirect emissions from electrical power consumption contribute approximately 6% to overall CO₂ emissions.

The data both above and in the following section are based on the "Getting the Numbers Right" (GNR) database. Key drivers of emissions and performance are also included. The database provides industry and policy makers with current performance figures to aid their analyses and decisions.

The efforts to reduce our CO₂ emissions have been an integral part of improving the sustainability of our businesses and meeting the needs of our customers.

The European cement industry in the EU27 (based on 2011 data)⁸

	2011	Unit
Clinker production	140	Million tonnes
Cement production	191	Million tonnes
Absolute emissions of CO ₂ (excluding CO ₂ from power generation)	122	Million tonnes
Volume of alternative fuels used	7.66 (25.6% of total thermal energy consumption)	Million tonnes
Volume of biomass used	2.15 (8.7% of total fuels thermal energy consumption)	Million tonnes
Use of alternative raw materials in Portland or blended cements	47.8	Million tonnes
Total thermal energy consumption (all fuel sources combined)	12.8	Million tonnes of oil equivalent (roughly equivalent to the energy consumption of Ecuador)
CO ₂ per tonne of clinker	849	Kg CO ₂ /tonne clinker
Average thermal energy consumption	3,730 ⁹	MJ/tonne clinker
Average electrical energy consumption	114	kWh/tonne cement

⁸ For the purposes of meaningful reporting, the definition of cement used in the GNR database differs slightly from that in common use. In this document, cement and cementitious products are considered equivalent.

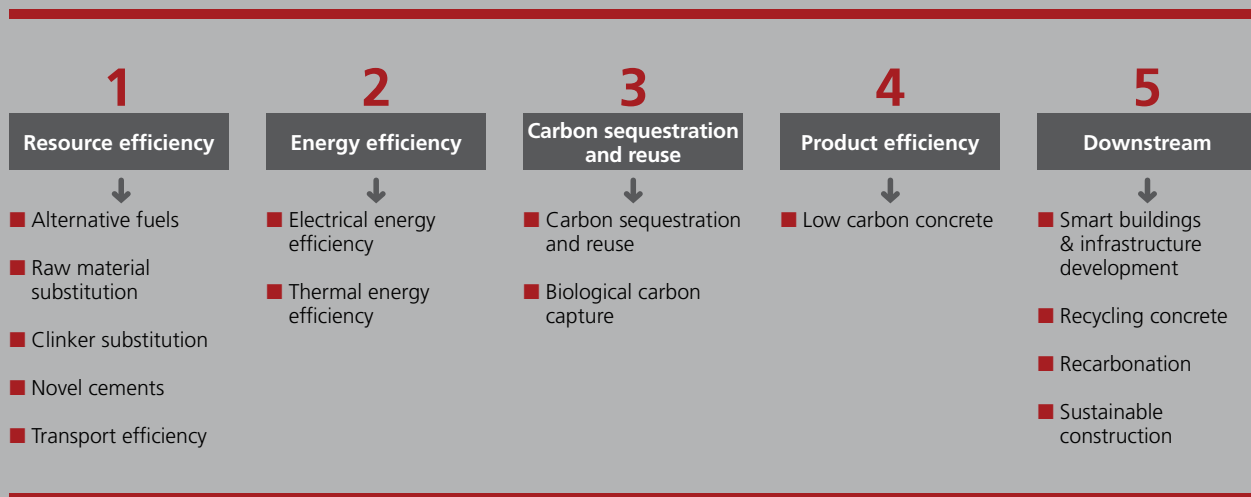
⁹ Based on grey cement



FIVE PARALLEL ROUTES



This 2050 roadmap is based on 5 parallel routes that can each contribute to lowering emissions related to cement production, as well as concrete production. The first 3 routes are quantified in this roadmap. The final 'product efficiency' and 'downstream' routes look at how cement and concrete can contribute to a low carbon society, providing a connection from this roadmap to the construction sector.



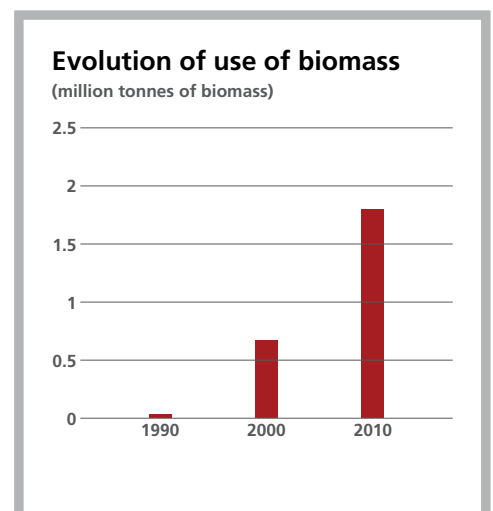
1 Five Parallel Routes: RESOURCE EFFICIENCY

1.1 Alternative fuels

In brief:

- Alternative fuels, including a high proportion of waste products, are increasingly being used and now represent almost a third of all fuels in the EU cement industry.
- Cement production is ideal for the uptake of waste such as tyres, sludge, sawdust and other types of waste.
- The European cement industry has steadily increased its use of alternative fuels (a sevenfold increase since 1990) to over 7 million tonnes in 2010.
- Together with energy recovery, the fuel ashes are entirely used as raw material in cement production.
- To increase use of alternative fuels, access to waste and biomass must also increase. This will be helped by:
 - Promoting a better understanding of the opportunities and benefits of co-processing.
 - Introducing legislation to promote co-processing for appropriate waste materials.

Cement production is energy-intensive and currently a mix of coal, petcoke, biomass and waste materials is used as a fuel source. Use of alternative fuels like biomass or waste materials has an immediate impact on the industry's carbon profile, and while the industry already uses large quantities of such materials, this may well be increased in the future. The unique process and energy requirements of the cement industry enable use of fuel mixes that would not be suitable for many other industries. This ability to mix fossil fuels like coal or gas with waste materials, biomass and industrial by-products is beneficial both from a resource efficiency and security of supply point of view.





The unique process and energy requirements of the cement industry enable use of fuel mixes that would not be suitable for many other industries.

In Europe, the cement industry has replaced a large part of its traditional fuel sources with biomass or waste. From a technical point of view, much higher substitution rates are possible, with some plants using up to 80% alternative fuels¹⁰.

Apart from direct effects of replacing carbon-intensive fossil fuels with lower-carbon-intensity of alternative fuels, there can also be indirect benefits. Waste materials disposed of via landfill or by incineration give rise to their own greenhouse gas emissions, such as methane in landfill gas. By using these materials as alternative fuels in cement plants, harmful decomposition-related emissions are avoided. Use of waste as an alternative fuel in cement kilns contributes to lowering overall CO₂ emissions by replacing fossil fuels and their related CO₂ emissions with waste materials, which would otherwise have to be incinerated or landfilled with corresponding emissions of greenhouse gases. Typical alternative fuels classed as waste products include waste tyres, waste oil and solvents,

pre-treated industrial and domestic waste, and plastic, textile and paper waste. There may also be transport-related benefits if local alternative fuels replace imported fossil fuels.

Pure carbon-neutral biomass fuels used in the cement industry today include animal meal, waste wood, sawdust and sewage sludge. Besides these fuels, many other organic waste materials are utilised as fuels in the cement industry globally, but to a lesser extent. Wastes containing biomass are mainly pre-treated industrial and domestic products (containing organic fibres, textiles and paper).

Co-processing waste offers a cheaper solution than investing in dedicated facilities, which require a huge capital investment and in which operating costs tend to be higher.

¹⁰ On an average annual basis

Sewage sludge and cement production

Sewage sludge is a by-product of waste water treatment. Until recently, the main solutions for sewage sludge were open dumping, landfill disposal or use in agriculture. However, there is increasing concern about organic residues in sewage sludge, making its use in agriculture questionable. Sewage sludge can also be used as both an alternative fuel source and raw material in the high-temperature clinker manufacturing process, destroying organic residues. It is important to note that there is a surplus of sludge, so the need for alternative forms of processing is becoming all the more acute.

The Netherlands and Spain are just two examples of countries where the cement industry is providing a solution for sewage sludge. Since March 2000, the ENCI cement plant located in Maastricht (the Netherlands) has been working together with the Limburg Purification Board to develop ways of receiving pre-treated sewage sludge from their sewage water treatment plants (following treatment in the Board's own thermal sludge dryers). Today, 80,000 tonnes of dried sewage sludge is co-processed annually in a kiln with a capacity of 865,000 tonnes of clinker per year.

In 2005, the cement sector in Catalonia (Spain) reached an agreement with the Catalan administration, trade unions and local councils to launch a trial to monitor the environmental behaviour of thermally dried sewage sludge from the Barcelona area as an alternative fuel in cement plants. The aim was to use more than 60,000 tonnes of dried sewage sludge every year as a petcoke substitute, providing a solution for the high volume of sewage sludge that cannot be used for agricultural purposes.

In addition, a cement plant in Spain is drying sewage sludge using exhaust gases from the clinker cooler, and then uses the dried sewage sludge as alternative fuel for the kiln. Other national governments should follow suit to maximise the potential of sewage waste by making it available for use in cement manufacture.



Challenges

In order to use biomass as a fuel, it has to be affordable, secure and continually available. As industries try to reduce their CO₂ emissions and demand for green power grows, there will be increased competition with other industry sectors (power plants, steel industry, biomass boilers) over access to biomass.

Higher replacement rates of fossil fuels by alternative fuels will be facilitated if waste legislation, in the EU and its Member States, restricts landfill and allows controlled waste collection, treatment and alternative fuel production. Better understanding and social acceptance of using waste as an alternative fuel in cement plants is also key.

Potential savings

It has been estimated that by 2050, 40% of kiln energy could potentially come from traditional sources, i.e. coal (30%) and petcoke (10%). While 60% of kiln energy could potentially be provided by alternative fuels of which 40% could be biomass. This fuel mix would lead to an overall decrease of 27% in fuel CO₂ emissions. In order to achieve this level of reduction, a number of policy modifications are required, which are outlined below.

Policy recommendations

- Implement a waste policy that recognises and rewards the benefits of co-processing and its close integration with other industries.
- Ensure a level playing field for the use of biomass waste by removing subsidies that favour one industry over another.
- Implement waste legislation to avoid landfill of waste that has a calorific value or contains other recoverable resources.
- Introduce a revised waste hierarchy including co-processing overlapping energy recovery and recycling.
- Develop an R&D policy promoting recovery of materials with calorific potential from waste for co-processing.

Better understanding and social acceptance of using waste as an alternative fuel in cement plants is also key.

1.2 Raw material substitution

Despite all efforts, cement will remain a product based on natural components and will continue to use natural resources to a certain extent. Therefore, there is a need to ensure the implementation of a community-wide harmonised process for the permitting of new quarries.

In brief:

- 60% of the industry's emissions are 'process emissions' caused by decarbonation of limestone during the production process.
- Limestone needed to make clinker can be partially substituted by a range of alternative calcium containing materials, including waste and industrial by-products, which are already increasingly being used.
- Many of the alternative materials are ashes provided by the combustion of alternative fuels.
- Further research into the use of alternative raw materials and ensuring access to these materials should be supported.

The main raw material used in cement production has traditionally been limestone. Limestone is abundantly available, but over 60% of the industry's CO₂ emissions are caused by transformation of limestone into lime, called "decarbonation". Accordingly, part of the route towards a low carbon concrete-built environment can involve limestone substitution.

The cement industry already replaces some of its raw natural resources with waste and by-products from other industrial processes. Selected waste and

by-products containing useful elements such as calcium, silica, alumina and iron can be used as raw materials in the kiln, replacing natural substances like clay, shale and limestone.

Some waste materials have both a useful mineral content and recoverable calorific value. For example, sewage sludge has a low but significant calorific value, and yields ash that becomes a raw material used to make clinker.

In recent years, about 3-4% of raw materials used in the production of clinker in Europe consisted of alternative raw materials and ashes from fuel, totalling about 14.5 million tonnes per year.

The use of alternative raw materials offers numerous benefits, including a reduced need for quarrying and lower CO₂ emissions if the alternative materials have already been decarbonated.

In terms of volume, construction and demolition waste represents the largest single group of all waste types in Europe, and a substantial part of this waste is concrete. Cement production may be able to provide a solution by reintegrating crushed, or otherwise treated, concrete as a substitute for limestone.



Ashes from lignite or coal, blastfurnace slag, concrete crusher sand, aerated concrete meal and fractions from demolition waste have already been decarbonated and could be used as an alternative to 'virgin' limestone thus avoiding CO₂ emissions during its transformation to lime in the production process.

Challenges

The potential for waste product use is influenced by the raw materials available near the cement plant, which can vary significantly from site to site. High concentrations of silica, alumina, magnesium or sulphur can hinder large-scale use of alternative decarbonated raw materials, and the presence of volatile organic compounds (VOCs), trace elements content or variable compositions may cause further restrictions in some cases.

Moreover, the availability of such decarbonated raw materials can be limited. Further preparation steps, as is the case of concrete crusher sand, may improve the quality of the material, but will also increase costs. Providing sufficient storage capacity for alternative raw materials to ensure continuous operation additionally will require substantial investments.

Policy Recommendations

- Design and implement policies that reward the use of alternative materials to replace natural materials.
- Implement a waste policy that recognises and rewards the benefits of co-processing and industrial symbiosis.
- Implement waste legislation aimed at avoiding landfilling of waste that contains recoverable resources such as a useful mineral content and / or a thermal calorific value.
- Adopt policies that reward the use of local sources and widely available materials.
- Draft policies that reward use of waste based on the best available way taking into account the entire cycle assessment.
- Design R&D policies aimed at fostering the recovery of minerals from waste for co-processing.

Despite all efforts, cement will remain a product based on natural components and will continue to use natural resources to a certain extent. Therefore, there is a need to ensure the implementation of a community-wide harmonised process for the permitting of new quarries.

1.3 Clinker substitution

In brief:

- Clinker can be blended with a range of alternative materials, including pozzolans, finely ground limestone and waste materials or industrial by-products. The clinker-to-cement ratio (percentage of clinker compared to other non-clinker components) has an impact on the properties of cement so standards determine the type and proportion of alternative main constituents that can be used.
- To ensure the future use of other constituents, the cement industry is dependent on the local supply of these materials.

Cement production is energy-intensive and currently a mix of coal, petcoke, biomass and waste materials is used as a fuel source. Use of alternative fuels like biomass or waste materials has an immediate impact on the industry's carbon profile, and while the industry already uses large quantities of such materials, this may well be increased in the future. The unique process and energy requirements of the cement industry enable use of fuel mixes that would not be suitable for many other industries. This ability to mix fossil fuels like coal or gas with waste materials, biomass and industrial by-products is beneficial both from a resource efficiency and security of supply point of view.

The use of other constituents in cement and the reduction of the clinker-to-cement ratio means lower emissions and lower energy use.

Ordinary Portland cement can contain up to 95% clinker (the other 5% being gypsum). The current average clinker-to-cement ratio over all cement types in the EU27 is 73.7%¹¹.

Different cement types have different properties, including hardening time, early and late strength, resistance to salty conditions and chemically aggressive environments, heat release during curing, colour, viscosity and workability. The importance and relevance of these qualities depend on the desired application of the cement and concrete.

There is a need to ensure that all the cement manufactured is safe and durable as it will be

used in structures that are made to last at least 50 years or more. Thus, high durability of the final product concrete is a key property for sustainable construction. Cement in Europe must be manufactured according to the harmonised European Standard EN 197-1, which lists 27 common cements according to their main constituents. The theoretical clinker content of these cements in the European Standard can vary between 5% and 95%. Varying clinker content has an impact on the type of applications the cement can be used for.

Other materials that can be used:

- Natural pozzolans, such as clays, shale and certain types of sedimentary rocks.
- Limestone (finely ground), which can be added to clinker (without being heated and transformed into lime).
- Silica fume, a pozzolanic material and a by-product in the production of silicon or ferrosilicon alloys.
- Granulated blastfurnace slag (GBFS), a by-product of the pig-iron/steel production process.
- Fly ash, dust-like particles from flue gases of coal-fired power stations.

Challenges

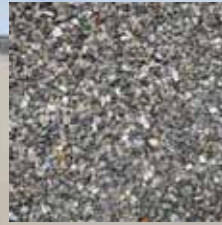
Availability

The availability of alternative materials that can be used as other constituents varies considerably. For example, granulated blastfurnace slag availability depends on the location and output of blastfurnaces for pig-iron production equipped with slag granulation facilities, whilst fly ash use is dependent on supply from sufficiently close coal-fired power plants. The availability of pozzolans depends on the local situation and only a limited number of regions have access to this material for cement production. Limestone is abundant worldwide and is easily accessible to most cement plants.

Standards & market acceptance

Cement standards serve to guarantee the performance of each cement type. The use of other constituents has an impact on the way the cement

¹¹ Source: For the purposes of meaningful reporting, the definition of cement used in the GNR database differs slightly from that in common use. In this document, cement and cementitious products are considered equivalent.



There is a need to ensure that all the cement manufactured is safe and durable as it will be used in structures that are made to last at least 50 years or more.

will perform in both the short and long term. The success of cements with a low clinker-to-cement ratio will also depend on market acceptance. Quality is crucial for building stability and, as such, a matter of public safety, e.g. bridges, sky scrapers as well as for the sustainability of investments into infrastructures and buildings.

Potential savings

A global clinker-to-cement ratio of 78% in 2006 meant that about 550-600 million tonnes of constituents other than clinker were used. The International Energy Agency (IEA)¹² estimated that in 2005, there were around 1,215 million tonnes of material suitable for clinker substitution globally (excluding pozzolan and limestone). On this basis, it seems that the use of other constituents could be doubled. However, this scenario is only hypothetical because it does not take into account that these quantities do not necessarily reflect the required quality or local market situation.¹³ There is also uncertainty regarding the future availability of clinker substitutes as well as the impact of environmental policy and regulation. For example, the future decarbonisation of the power sector could limit the availability of fly ash, or the application of Nitrogen Oxide(s) abatement techniques in coal-fired power stations could mean that the fly ash may be unusable as a constituent in cement due to higher NH₃ (ammonia) concentrations. Furthermore, some of these materials are already used in concrete, rather than cement, production. Finally, a life cycle cost analysis needs to be done to ensure that policies are based on the entire life cycle in order to avoid focusing solely on intermediate material impact.

At a European level, it is estimated that the clinker-to-cement ratio can be reduced to 70%, resulting in a further CO₂ saving of 4%.

Policy Recommendations

- Low-clinker cements can offer both environmental benefits as well as favourable product characteristics. Nevertheless, it is important that a whole life cycle approach is applied to public procurement rather than simply focusing on product footprinting or intermediate product impacts.
- Facilitate access to raw materials and enhancing waste and by-products recycling policies.
- Provide support for and access to R&D funding. In addition, a strong industry focus on innovative cements and concretes has the potential to respond to the requirements of sustainable and resource-efficient production and construction.

¹² Source: <http://www.wbcscement.org/pdf/technology/Technology%20papers.pdf>

¹³ Source: Development of State of the Art Techniques in Cement Manufacturing: Trying to Look Ahead (CSI/ECRA- Technology Papers), State of the Art Paper No 4: Reduction of clinker content in cement: long-term perspective

1.4 Novel cements

The European cement industry is highly innovative with large scale research centres in several countries and hundreds of patents filed each year. A number of low-carbon or very-low-carbon cements are currently being developed.

In brief:

- Several types of novel clinkers and cements using new production processes are being developed.
- The possibilities offered are exciting, but in the short to medium term, novel cements will probably mainly be used for niche applications.
- The obstacles of market acceptance, standards, volume and availability of raw materials will have to be overcome.

The European cement industry is highly innovative with large scale research centres in several countries and hundreds of patents filed each year. A number of low-carbon or very-low-carbon cements are currently being developed. While some daunting hurdles and validation of product properties remain, there is ultimately the exciting prospect of entirely new types of cement. However, these new cement types have neither been shown to be economically viable, nor tested on a large scale for long-term suitability and durability. Nor have these products been accepted by the construction industry, where strong materials and strict building standards reign supreme. When the first of these plants go to full scale production, initial applications are likely to

be limited and focused on niche markets, pending widespread availability and customer acceptance.

Several parallel novel cement types are being developed including:

- Magnesium silicates rather than limestone (calcium carbonate).
- Calcium sulfo-aluminate belite binders.
- A mixture of calcium and magnesium carbonates and calcium and magnesium hydroxides.
- New production techniques, using an autoclave instead of a kiln and a special activation grinding that requires far less heat and reduces process emissions.
- Dolomite rock rapidly calcined in superheated steam, using a separate CO₂-scrubbing system to capture emissions.
- Geopolymers using by-products from the power industry (fly ash, bottom ash), steel industry (blastfurnace slag), and concrete to make alkali-activated cements. Geopolymer cements have been commercialised in small-scale facilities, but have not yet been used for large-scale applications.



There is a future for new or novel cement types, but given the early stage of their development, it will take quite some time before large-scale production becomes a reality.

Some of these novel cements are showing early potential, but it is important to remember that they have yet to be produced in the kinds of volumes the global construction industry needs. To produce cement in the billions of tonnes that is required by the construction industry takes huge investment and rigorous testing. Establishing fitness for purpose of any cement is neither a simple nor a linear undertaking, and the more unfamiliar the cement type, the more research will be needed.

Challenges

Availability of raw materials

The main raw material for ordinary Portland cement, limestone, is abundantly available across the globe. However, some of the materials needed for novel cements might not be available in sufficient quantities or in the right places, meaning raw materials would have to be shipped over long distances or could require considerable treatment before use.

Proven performance

Cements have been around since Roman times, but while the technology has changed substantially, the process still relies on the same basic raw materials and volcanic heat (around 1,450°C) to bring about the fundamental chemical reaction that turns cement into

a binder. Current cement types, including those that use by-products, are tried and tested. It goes without saying that any material that plays such a crucial role in our lives needs to be safe, but it also needs to be long-lasting, without requiring excessive maintenance.

Volume

It takes time to gain market acceptance and develop the necessary production capacity to have a meaningful impact on the industry's overall emissions.

Potential savings

There is a future for new or novel cement types, but given the early stage of their development, it will take quite some time before large-scale production becomes a reality. Furthermore, they are likely to be used in non-structural niche applications for the foreseeable future. Nevertheless, a 5% share of total cement production for novel cements has been included, namely 11 million tonnes. Novel cements will still require energy for their production and will not be zero carbon products. The exact potential carbon reduction is not known at this time but for many of the more promising technologies, it is estimated to be around 50%, which has been applied in the modelling for the expected 5% of total cement production.

1.5 Transport efficiency



reduce transport related emissions and expects to make significant progress on reducing emissions related to heavy haulage by mixing water and land based transport modes as well as improving transport efficiency.

A range of measures can be taken to reduce transport related emissions:

- In most cases, cement can be transported using efficient and low emission transport solutions, which should be encouraged.
- Building new plants near waterways or rail networks can reduce the share of road transport.
- If the amount of alternative fuels and clinker substitutes increases, efficient and low emission transport solutions have to be put in place to transport alternative materials to the cement plant.
- The share of inland waterway and rail transport can be increased at some plants with easy access to waterways or rail hubs.

In brief:

- Cement is a bulk product and road transport over long distances is not economically viable.
- Maritime and river bulk transport is very cost effective, which puts many European plants near sea and inland ports at risk of competition from cheap imports.
- The increased use of inland waterways and rail networks will decrease transport emissions.
- Using more locally sourced alternative fuels will lower transport emissions.

Cement is a heavy product and so are its raw materials. As the industry decarbonises its plant operations, transport could come to represent an increasing proportion of the cement industry's greenhouse gas (GHG) impact. However, the industry is continuously working on solutions to

Potential Savings

If the share of road transport is reduced to 50% by 2050, with both rail and water representing 23% each, combined with innovation in the transport sector, it has been estimated that transport related emissions can be halved.

Policy Recommendations

- Adopt a holistic industrial policy approach.
- Encourage the use of railway networks and inland waterways.
- Allow concentrations of interdependent industries in close proximity.
- Allow the development of quarries and cement plants in close proximity.

The industry is continuously working on solutions to reduce transport related emissions and expects to make significant progress on reducing emissions related to heavy haulage by mixing water and land based transport modes as well as improving transport efficiency.

2 Five Parallel Routes: ENERGY EFFICIENCY

2.1 Electrical energy efficiency

In brief:

- Cement manufacturing mainly uses electricity to crush and grind raw materials, to transport large quantities of gases and materials and to grind cement.
- Continuous improvements to the production process will lower the amount of electricity used.
- Deploying Carbon Capture technology could increase electricity consumption by 50-120%.

Cement production requires electrical power at several stages, from crushing of raw materials over clinker production and cement grinding.

In a cement plant, power for different operations is typically distributed as follows:

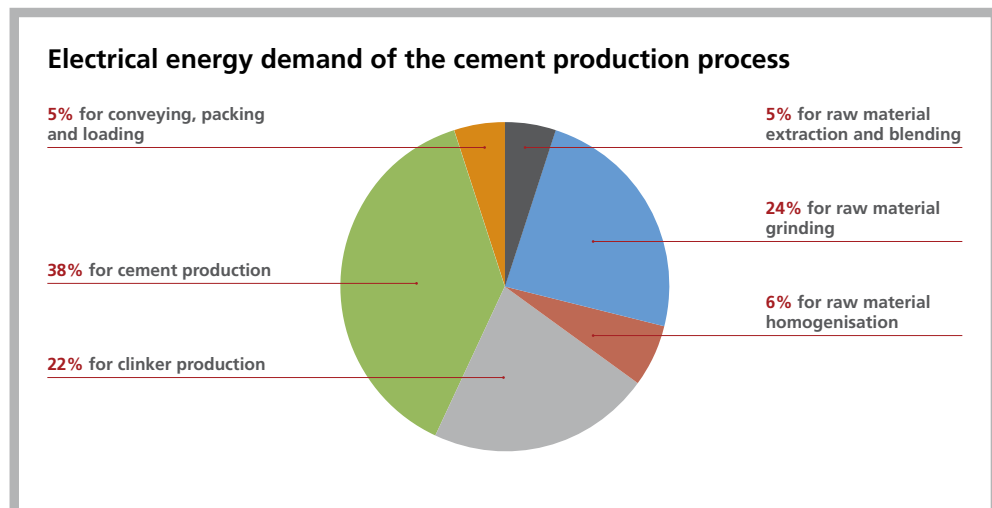
- 5% for raw material extraction and blending
- 24% for raw material grinding
- 6% for raw material homogenisation
- 22% for clinker production
- 38% for cement production
- 5% for conveying, packing and loading


Replacing older plants with more modern and efficient technologies and continually modernising existing plants will result in improved electrical performance. For example, the application of enhanced grinding techniques and waste heat recovery processes, as well as the use of modern clinker cooler technology and variable speed drives will reduce the levels of electrical energy required.

Equipment in existing cement plants is continually modernised, meaning that after a period of 20-30 years, most of the original equipment has either been replaced or modified (e.g. preheater cyclones, clinker cooler, dedusting equipment).

Challenges

Measures that increase thermal efficiency often need more electrical power. For example, installation of modern grate coolers yields a reduction in thermal energy use, but increases electrical energy consumption.





It has been estimated that by modernising existing plants, replacing older plants and constantly introducing innovations, average electricity use could be further reduced.

Lowering limit values for dust emissions also requires more power for dust separation, regardless of which technology is applied. Reducing levels of other pollutants (like NO_x or SO_2) will necessitate use of additional equipment consuming electricity.

Furthermore, if Carbon Capture & Storage were to be applied on a large scale, the power consumption of cement manufacturing could increase by 50%-120% at plant level¹⁴.

Cement performance has an important impact on power consumption. Indeed, the higher a cement's strength development potential, the finer it has to be ground, and the greater its specific power consumption¹⁵. Furthermore, the production of certain cement types that use hard to grind by-products, such as blastfurnace slag, also requires more electrical power.

Potential savings

As a whole, European cement plants are very energy efficient and a fundamental change in current cement-producing technology, with a view to achieving a significant reduction in electrical energy consumption, is unlikely. Nevertheless, it has been estimated that by modernising existing plants, replacing older plants and

constantly introducing innovations, average electricity use could be further reduced.

The model included in this roadmap assumes a total decarbonisation of the power sector by 2050 and all measures that will be taken to reduce our electricity consumptions do not have an impact on the carbon profile of the calculations. Nevertheless, in a bid to increase its competitiveness, the European cement industry continuously strives to reduce power consumption and will continue to do so.

Policy Recommendations

- Provide access to R&D funds to stimulate breakthrough technologies. For example making grinding more efficient.
- Integrate access to and development of public and private financing mechanisms in all policy initiatives allowing a faster market delivery of existing and new technologies.
- Ensure European industries have access to electricity at fair and affordable price levels (including taxes and fees), which means a liberalised electricity market is crucial.

¹⁴ & ¹⁵ Source: Development of State of the Art Techniques in Cement Manufacturing: Trying to Look Ahead (CSI/ECRA-Technology Papers), State of the Art Paper No 2: Electric efficiency of cement production: state of the art and long-term perspective

2.2 Thermal energy efficiency

In brief:

- Cement manufacturing requires raw materials to be heated to 1450°C and is thus rather energy intensive, even if thermal energy only accounts for approximately 35% of the cement industry's CO₂ emissions.
- Continuous improvements to production facilities have almost halved our energy use since the 1960s. Most European plants now use state-of-the-art technology.
- The few remaining older wet kilns will be replaced by more modern plants and concentration of production in fewer, larger, plants will lead to further reduced energy consumption.
- Waste Heat Recovery systems are being investigated and should be encouraged.
- Based on GNR data for the year 2010, the European average thermal energy needed to produce a tonne of clinker was 3,730 MJ.

The lifetime of cement kilns is usually 30-50 years. New kilns are therefore predominantly built in places where market growth potential is thought to be substantial. Therefore, in the past decade most new plants have been built in Asia, Africa, the Middle East and some parts of Eastern Europe. Often after 20-30 years, most of the original equipment (e.g. preheater cyclones, clinker cooler, burners etc.) has been replaced and plants are constantly being fitted with modern technology. This is typically the case in Europe, where kilns are relatively old but still efficient. The average size of kilns in Europe and North America is around 0.9 to 1.1 million tonnes of clinker production per preheater kiln with precalciners (PH-PC), compared to 1.9 million tonnes of production per site per year in Asia.

Under optimised and regular conditions, the best energy efficiency today – around 3,300 MJ/t clinker – can be achieved with preheater kilns with precalciners (PH-PC). Modern PH-PC kilns have a higher production capacity than older installations, which also contributes to greater energy efficiency across the sector.

Long dry kilns without preheater towers consume around 33% more thermal energy, and old wet kilns consume up to 85% more energy than PH-PC kilns.

Continuous innovation in production methods will reduce energy use over time, thus overall energy use in Europe is expected to decrease as the few remaining wet plants are phased out, average kiln size increases and incremental innovation is implemented.

Another area where progress can be made is Waste Heat Recovery (WHR). Already common in China because of a specific plant design, newly built or retrofitted plants in Europe could be equipped with WHR systems and use the heat power generation, provided that installing a WHR system is viable. The main limit to using WHR is the initial investment and a long payback period, although this is dependent on local electricity costs.

Modern PH-PC kilns have a higher production capacity than older installations, which also contributes to greater energy efficiency across the sector.



Continuous innovation in production methods will reduce energy use over time, thus overall energy use in Europe is expected to decrease as the few remaining wet plants are phased out, average kiln size increases and incremental innovation is implemented.

Challenges

Many thermal energy-reducing measures cause an increase in power consumption. For the time being, the dry process with multistage preheating and precalcination technology is considered state-of-the-art. Breakthrough technologies that could lead to significantly higher thermal efficiency are not yet in sight.

Furthermore, the increased use of alternative fuels can negatively affect energy needs per tonne of clinker when they have higher moisture content and/or lower overall heat content. Possible other uses of waste heat, like co-generation to generate power or dry algae might also have an impact on power consumption.

Potential savings

Average kiln capacity of cement plants will continue to increase because new kilns are typically built with higher capacities, and existing smaller kilns will increasingly be replaced with larger more modern ones. Breakthrough technologies, such as fluidised beds, that could yield significantly higher thermal efficiency are not yet on the horizon.¹⁶

Taking into account the increased use of alternative fuels, average thermal energy consumption per tonne of clinker is expected to reach 3.3 MJ/tonne by 2050.

Policy Recommendations

- Provide access to R&D funds to stimulate breakthrough technologies.
- Integrate access to and development of public and private financing mechanisms in all policy initiatives allowing a faster market delivery of existing and new technologies.
- Support a shift to waste heat recovery (WHR) and facilitate this through an efficient and speedy permitting process.
- Adopt a policy that provides WHR with an equivalent support mechanism as Combined Heat and Power (CHP) and renewable energy, such as Energy Efficiency Certificates as already available in a few Member States (e.g. Italy). WHR should not be disincentivised by tax on generated electricity.

¹⁶ Development of State of the Art Techniques in Cement Manufacturing: Trying to Look Ahead (CSI/ECRA-Technology Papers), State of the Art Paper No 1: Thermal efficiency of cement production: state of the art and long-term perspective

3

Five Parallel Routes: CARBON SEQUESTRATION AND REUSE

3.1 Carbon Sequestration and Reuse

In brief:

- Even with the most efficient processes, a part of the CO₂ emissions linked to cement production cannot be avoided.
- The possibility of carbon capture is currently being evaluated in several large scale integrated Carbon Capture and Storage (CCS) projects in the power sector¹⁷.
- Initial results show currently available technologies could capture 90% of CO₂ emissions.
- Captured carbon could be transported to a storage site or used in other production/ downstream processes e.g. to grow algae as biomass that can be used as a fuel.
- Carbon capture would increase production costs by 25 to 100%, require substantial investments and require the use of additional electricity.
- CCS is only realistic if the CO₂ transport infrastructure and storage sites are suitable and approved for that purpose.

Previous sections have outlined how the cement industry has already reduced its emissions and will continue to do so through conventional resource and energy efficiency measures in the future.

Outside conventional technology, one possible breakthrough, long-term solution is carbon capture, whereby CO₂ is captured at the source and then re-used or stored.

There are several on-going research projects testing the feasibility of using carbon capture in the cement industry and exploring different ways of capturing CO₂.

■ *Post-combustion capture technologies*

Post-combustion CO₂ capture is an end-of-pipe mechanism that would not require fundamental changes to the kiln-burning process, thus making it an option for both new kilns and retrofits.

- The most promising post-combustion technology is chemical absorption. High capture rates in other industries have been achieved using amines and other chemical solutions.
- Membrane technologies may also be an answer if suitable materials and cleaning technologies can be developed.
- Carbonate looping, an absorption process in which calcium oxide is put into contact with the combustion gas containing CO₂ to produce calcium carbonate, is a technology currently being assessed by the cement industry as a potential retrofit option for existing kilns, and for the development of new oxy-firing kilns. In addition, synergies with power plants can also be generated (deactivated absorbents of power plants could be reused as an alternative raw material in cement kilns).

■ *Oxyfuel combustion*

Using oxygen instead of air in cement kilns would result in a comparatively pure CO₂ stream. This technology is still in its infancy and requires extensive investigation. Oxyfuel combustion would change the atmosphere in the kiln and potentially influence how clinker is produced. Current laboratory studies showed that the cement properties remain unchanged from oxyfuel production. An oxyfuel kiln would represent a significant shift in clinker production. However the retrofit of a cement plant with oxyfuel technology seems feasible with a certain effort

¹⁷ Global CCS Institute : Large-scale Integrated CCS Projects <http://www.globalccsinstitute.com/projects/browse>

It is expected that the cost of CCS will fall in the future with technical and scientific advances, but both increased investment and operating costs will remain substantial.

(e.g. modification burner/cooler etc, implementing air separation/CO₂ purification). Nevertheless the planning of a pilot plant still requires some detailing. To capture carbon dioxide (CO₂) it is first separated from other gases resulting from combustion or processing. It is then compressed and purified to make it easier to transport and store or re-use.

If capturing a substantial part of CO₂ emissions is technically possible, one still has to solve the issue of what to do with the CO₂ that was captured. Three possible scenarios are envisaged:

Carbon Capture Utilisation (CCU)

After capture CO₂ can be used in a series of processes and industries such as the production of carbonated beverages. However, this offers very limited potential given the volume of CO₂ emitted by the cement industry, and the fact that only a very small amount of this CO₂ can be utilised by such industries and processes.

Carbon Capture Valorisation

CO₂ could also be used as raw material in a range of processes that are currently being developed including:

- Construction materials converting CO₂ into carbonates and bicarbonates using an enzyme catalyst
- Carbonate polymers (bio-plastics)
- Feedstock for solvent manufacturing
- Methanol Synthesis fusing CO₂ and H₂ generation

Carbon Capture & Storage

Carbon Capture and Storage, or CCS, is the commonly used term where captured CO₂ is transported to an underground storage facility and permanently stored in an appropriate geological formation. This is seen as a last resort and using or creating value with CO₂ is preferred. However, the possible quantities of CO₂ from carbon capture are enormous and it is not clear if utilisation and valorisation capacities can absorb these quantities.

Potential savings

Carbon capture in the cement industry is still at the research & development stage. In the power sector it is currently being tested at a series of pilot and demonstration plants. Nevertheless, the potential of CCS looks promising. In order to achieve an 80% reduction in CO₂ emissions by 2050, taking into account all other measures, and without any



other breakthrough technology, 85% of all clinker production would have to be equipped with carbon capture technology, which amounts to 59% of all plants since carbon capture would be deployed at larger plants.

Challenges

Cost & competitiveness

Building new plants equipped with carbon capture technology and retrofitting existing plants will involve substantial capital expenditure as well as significantly increased operating costs. With today's state of knowledge and based on the current situation cement produced in a carbon capture-equipped plant seems not as competitive as cement produced in a non-carbon capture-equipped plant. Under certain conditions, like CO₂ reuse, abandonment of secondary abatement techniques for NO_x emissions or increased alternative fuel use (in the case of oxyfuel), carbon capture plants could become economic.

The exact capital expenditure needed per plant is hard to determine at present, but is estimated to be around €330-360 million to deploy oxyfuel technology at a new 1 million tonne/year plant, about 100 million for retrofitting oxyfuel technology

and €100-300 million to retrofit an existing plant with post-combustion technology¹⁸. Operational costs of a plant equipped with post-combustion carbon capture technology are estimated to be double the cost of a conventional cement plant, while oxyfuel use would incur 25% higher operating costs. Additional costs would then be incurred for compression, transport, injection and storage. However, it is expected that the cost of CCS will fall in the future with technical and scientific advances, but both increased investment and operating costs will remain substantial.

Finally, carbon capture could be applied in the cement industry only if the international political framework effectively limited the risk of carbon leakage (relocation of cement production to countries or regions with fewer constraints).

A complete CCS chain

Capture technologies can only be useful if a full CCS chain is available, including transport infrastructure, access to suitable storage sites, a legal framework for CO₂ transport, storage, monitoring, verification, and licensing procedures.¹⁹

¹⁸ Source: European Cement Research Academy (ECRA)

¹⁹ Source: ECRA

European, national, regional and indeed local support would be needed to push CCS beyond the research stage. CCS would also require the support of local communities near storage sites to avoid a 'not in my back yard' scenario.

CO₂ transport

Captured CO₂ is compressed into a liquid and then transported by pipeline or road tanker and shipped to be stored deep underground. CO₂ is already transported this way for commercial purposes. A pipeline ensures lower emissions but, to date, there is no pipeline network dedicated to the transport of CO₂. If CO₂ were to be transported via road or rail tankers, the environmental impact of that transport would also have to be taken into account. Cement kilns in industrialised regions could be connected to grids more easily than plants in non-industrialised areas. However, concentrating production in a small number of large plants is not a viable option from an economic or environmental point of view, given the cost and emissions related to transporting cement or clinker.

Storage

CO₂ could be stored in depleted gas and oil fields, in deep saline aquifer formations, or injected into declining oil fields to increase the amount of oil recovered, a process known as enhanced oil recovery (EOR). Storage sites are typically several kilometres under the Earth's surface.²⁰

Clearly, the ability of storage sites to retain injected CO₂ is essential to the success of any CCS project. Storage sites would, therefore, have to be very carefully selected and monitored to ensure the highest level of confidence in permanent storage. This means that only specific locations, not necessarily in close proximity to cement plants, could be considered for carbon storage.

Additional energy requirements

Uptake of CCS technology by the cement industry would mean a significant increase in power consumption²¹. For CCS to make sense from an emissions perspective, additional power requirements would have to be supplied by low or net zero-carbon power generation.

Acceptance and legal framework

Public awareness of CCS is currently low, and the public has not yet had the chance to form any firm opinion on CCS and its role in mitigating climate change. European, national, regional and indeed local support would be needed to push CCS beyond the research stage. CCS would also require the support of local communities near storage sites to avoid a 'not in my back yard' scenario.

Policy recommendations

Carbon capture is currently one of the most promising new technology options to reduce CO₂ emissions in the cement industry and certainly the single solution that will have the biggest impact. However, in order to be able to deploy CCS solutions in the short to medium term, policy support would be needed at several levels, including:

- Research and development on all aspects related to CCS need to be supported and funded to accelerate greenhouse gas reduction in cement manufacture.
- Finance for new research to develop alternative ways to use the captured carbon emissions.
- Storage sites would need to be identified and developed with transport solutions, such as a dedicated pipeline network, put in place.
- Public acceptance of CCS would need to be achieved through concerted information campaigns and dialogue with all stakeholders.

Also, as shown in the model, the implementation of such policies would be essential to enable the cement industry to deploy CCS and thus reduce its emissions beyond the 32% it can achieve by more traditional means.

²⁰ Source: Shell

²¹ Source: WBCSD/CSI-ECRA, 2009

3.2 Biological carbon capture

Research projects will help to determine the functional and economic feasibility of industrial organic biomass production and how to incorporate this technology into the manufacture of cement.

In brief:

- Several research projects are underway to test the use of algae as a means to capture CO₂.
- The algae absorb CO₂ and are later dried and can be used as a fuel.

A promising alternative to CCS is using algae to 'eat' CO₂ emissions and produce fuel at the same time. Because of their substantial emissions, cement plants would be ideally suited for deployment of this innovative technology. Several projects, including large-scale undertakings in Spain and France, are currently underway to test the technology.

CO₂ from the chimney stack is fed into open reservoirs containing algae or into a dedicated closed system. Like all green terrestrial plants, microalgae grow by photosynthesis and their development requires light (natural or artificial), CO₂, water and some nutrients (mineral salts). The more CO₂ is fed to the algae, the better they grow.

The algae can then be harvested and dried (possibly using waste heat from the cement plant), before being used as a fuel for the cement kilns. Alternatively, algae biomass can be processed into

third-generation biofuels, bio-plastics or high-value-added compounds like antioxidants, lipids or proteins.

Challenges

The technology is still at a very early stage of development. Research projects will help to determine the functional and economic feasibility of industrial organic biomass production and how to incorporate this technology into the manufacture of cement. Applications of biological capture of CO₂ emissions at the scale of cement plants must address the sustainability of significant demands on land use and resource use.

Potential savings

It is too early to make any accurate predictions on potential CO₂ savings.

Policy recommendations

Algae technology offers a solution for CO₂ capture, as well as biomass fuel production that could potentially be suitable for smaller plants where CCS deployment is not an option. The research is, however, still at quite an early stage. Further research would need to be encouraged to discover its full potential.

4

Five Parallel Routes: PRODUCT EFFICIENCY

4.1 Low carbon concrete

In brief:

- After cement manufacturing, several techniques and processes are used that further improve the environmental performance of concrete.
- Techniques include using high performance cements to optimise cement use per tonne of concrete, locally sourcing of aggregates, optimising admixtures and concrete composition at the concrete mixing stage.
- Modern high strength concretes can reduce the volume of concrete needed to create a specific structure.
- None of these have been included in the CO₂ reduction model as they do not relate to reducing the impacts of cement manufacturing itself.

Concrete is already a low carbon product compared to many other common construction materials. The vast majority of cement is used as a binder in concrete; it is mixed with water and aggregates to make concrete. Various options to reduce the carbon footprint of cement are covered in the first three parallel routes presented here, but to further reduce its impact, it is important to look at the whole life cycle, including how cement is used in concrete. Indeed, there are several ways to reduce the environmental footprint of concrete:

Material sourcing

Aggregates and recycled materials from construction and demolition waste are relatively low-cost products and average delivery distance is less than 40 km. In environmental and economic terms, local sites serve local markets. Moreover, the price tends to double beyond a delivery radius of about 40 km. In order to keep transport emissions low, aggregates have to be sourced locally.

High-performance cements resulting in reduced cement content in concrete

A theoretical possibility for reduction of CO₂ in concrete buildings is use of high-performance cements instead of conventional cements. Use of high-strength cements could lower to some extent the amount of cement needed to make the same quantity of concrete, in spite of the concrete having a higher clinker content.

Extensive research is being conducted to test new combinations of aggregates for high-strength cements, but the cement content itself has a strong influence on the workability and durability of the concrete. The cement paste component causes a dense microstructure and guarantees the alkalinity of the concrete, which prevents corrosion of reinforcing steel. For these reasons, minimum cement contents are defined in regulations and standards for concrete constructions.

Admixtures

In addition to cement, gravel, sand and air, modern concrete contains one or more admixtures. Admixtures are chemicals added in very small amounts to concrete to modify the properties of the mix in its plastic and/or hardened state. Today, approximately 80% of ready-mixed and precast concrete production is modified with a concrete admixture. The quantity of admixture included is usually based on the cement content and for most admixtures are in the range of 0.2-2.0% by weight.

The main sustainability benefits of admixture use are:

- Optimised mix design - reducing embodied CO₂, water content and energy by enhancing the effectiveness of the cement component.
- Increased fluidity - decreases vibration noise and energy requirements during placement.



Extensive research is being conducted to test new combinations of aggregates for high-strength cements, but the cement content itself has a strong influence on the workability and durability of the concrete.

- Reduced permeability - increases the durable life of the concrete.
- Less damage from harsh environments – including marine, freeze-thaw and sub-zero conditions.
- Improved appearance – ensures a better finish and reduced need for service life repair.

By using admixtures to optimise mix constituents, the net improvement in water use and reduction in global warming potential of the concrete can be around 10-20%. In addition, some admixtures are derived from renewable raw material sources, such as corn or wood. In the latter case, the chemicals are produced from a by-product of paper pulp manufacturing, which in the past was considered a waste material sent for disposal.

Stringent testing has shown that admixtures are bound to concrete and do not leach out into the environment during the lifetime of concrete. Testing for admixtures in end-of-life scenarios has shown that even when old concrete is crushed, the admixture leaching rate is so slow that the admixtures biodegrade fast before they can reach significant concentrations in the natural environment.

Concrete composition

Finely divided material can be used in concrete in order to improve or achieve certain properties. These

materials include virtually inert additions (type I) and pozzolanic or latent hydraulic additions (type II). Additions to concrete are a class of materials that can be considered in the manufacture of concrete although this is very much dependent on the cement type used. The materials that can be used are sometimes the same as those used as constituents in cement manufacturing. The most frequently used additions to concrete are fly ash, a by-product of coal-fired power plants, ground granulated blastfurnace slag (GBFS), a residue of steel production, and silica fume, also known as microsilica. Less commonly used additions to concrete include natural pozzolans (or volcanic ash), metallurgical slag (known as GSCem), and rice husk ash.

Policy Recommendations

- Promote know-how in the ready-mix sector by establishing basic technical skills required for mix design.
- Invest in research to develop new technologies to test the durability of new concrete mixes more quickly.
- Encourage public procurement procedures which take into account the full carbon life cycle.

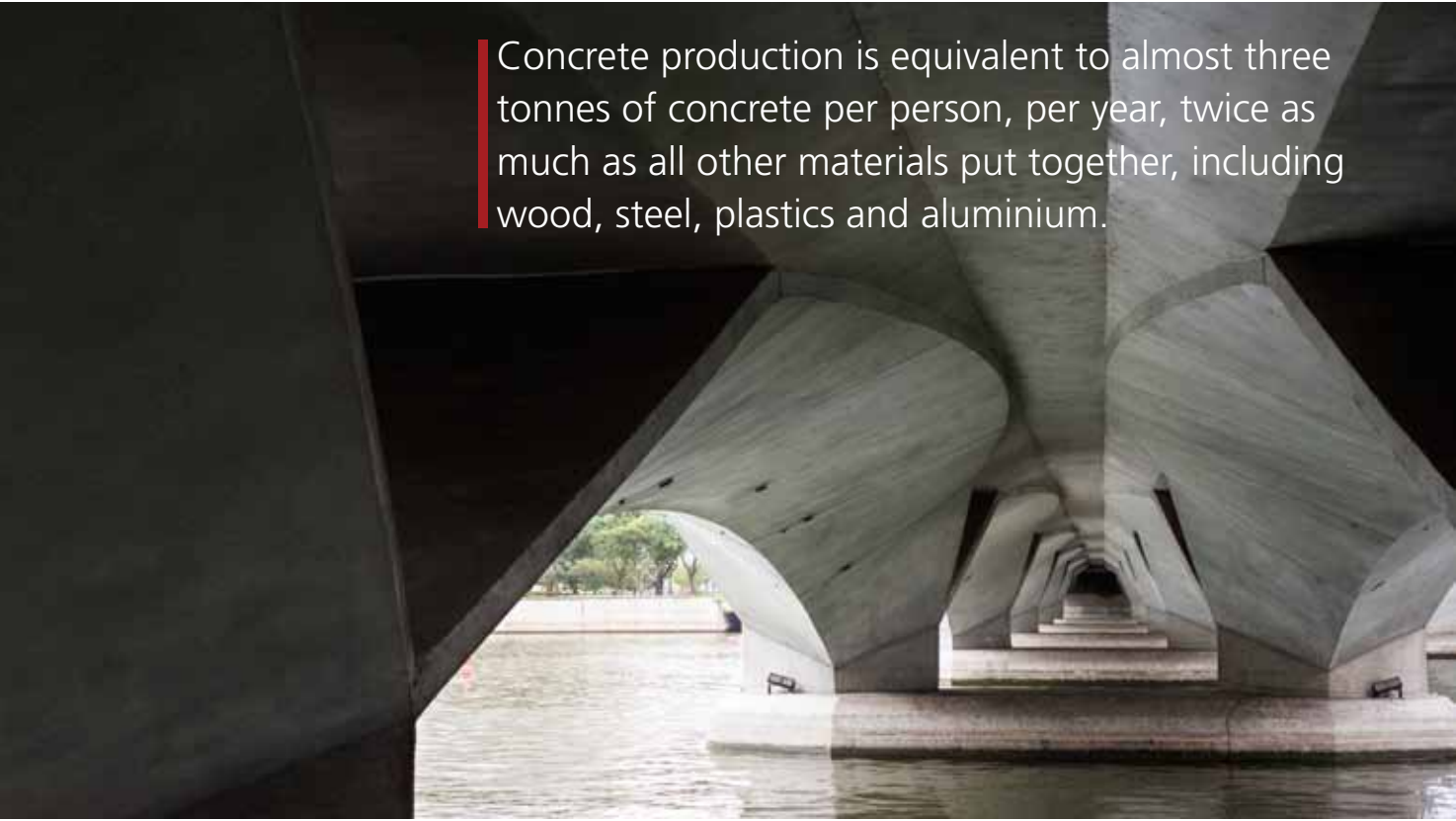
5 Five Parallel Routes: DOWNSTREAM

Cement is never used on its own. It is always mixed with other materials to make plaster, mortar and most importantly concrete. Therefore, the sector looks beyond the factory gates and carries out research and product development to improve the environmental performance of concrete and how to reuse or recycle concrete. None of the potential savings outlined in these sections were included in our calculations.

Why is concrete used?

Concrete is a composite construction material made primarily with aggregates, cement and water. It is the most commonly used manmade material in the world, its production equivalent to almost three tonnes of concrete per person, per year, twice as much as all other materials put together, including wood, steel, plastics and aluminium.²²

Concrete is widely used for architectural structures, foundations, walls, pavements, bridges, motorways, roads, runways, parking structures, dams, reservoirs, pipes, staircases, furniture and even in ships.



Concrete production is equivalent to almost three tonnes of concrete per person, per year, twice as much as all other materials put together, including wood, steel, plastics and aluminium.

²² <http://setis.ec.europa.eu/newsroom/library/technology-map-chapters/energy-efficiency-and-carbon-dioxide-emission-reduction-in-the-cement-industry>

Appropriate use of concrete surfaces can reduce local heating and thereby decrease the need for additional energy use for air conditioning.

There are many good reasons why concrete is so widely used all over the world:

■ *Strength and durability*

Concrete is used in constructions like buildings, bridges, tunnels and dams for its strength, which grows over time, as it is not weakened by moisture, mould or pests. Its durability makes concrete a key material for sustainable construction.

■ *Versatility*

Concrete can be used for a broad range of applications, including buildings, bridges, dams, tunnels, sewerage systems, pavements, runways and roads. It is infinitely mouldable, meaning that architects can realise their dreams and aspirations, constructing spaces and structures which can be elegant, vibrant and full of light.

■ *Excellent thermal mass*

Concrete walls and floors reduce the transfer of heat, reducing temperature swings. This lowers energy needs, from heating to air conditioning, offering year-round energy savings over the lifetime of the building.

■ *Low maintenance*

Being inert and compact, concrete does not attract mould or lose its key properties over time.

■ *Affordability*

In relation to other comparable building materials, concrete is less costly to produce and remains extremely affordable.

■ *Fire-resistance*

As it is naturally fire-resistant, concrete forms a highly effective fire barrier.

■ *Relatively low CO₂ emissions*

Specific CO₂ emissions from concrete and cement production are relatively small compared to other building materials.

■ *Energy efficiency in production*

Producing concrete uses less energy than producing other comparable building materials.

■ *Locally produced and used*

The relative cost of land transport usually limits cement and concrete sales to within 300km of a plant. This local use of cement and concrete minimises transport related emissions associated with other more globally traded construction materials.

■ *Albedo effect*

The high albedo (reflective qualities) of concrete used in pavements and building walls means more light is reflected and less heat is absorbed, resulting in cooler temperatures. This can help reduce the 'urban heat island' effect which affects some of the world's cities. Appropriate use of concrete surfaces can reduce local heating and thereby decrease the need for additional energy use for air conditioning.



5.1 Smart building and infrastructure development

Conventional buildings consume 200kWh/m²/year. By contrast, concrete technology, available today, enables buildings to be built that use 50kWh/m²/year.

In brief:

- Today, solutions exist for new buildings to be built with 60% less energy use and CO₂ emissions over the life cycle than conventional buildings constructed 20 years ago.
- New buildings can be built with deconstruction rather than demolition in mind.
- Parts of buildings could be re-used in their entirety or as modular elements.

Service life refers to the period of time a building can be expected to withstand normal conditions, if properly maintained. The expected service life of a building is usually relatively long, with many 100-year-old buildings still fully functional. But as needs evolve, infrastructure and buildings will often be replaced before the end of their lifetime. For example, today thermal efficiency of buildings is increasingly key, as is recyclability at the end of the building life. In both cases, concrete has a major role to play and can reduce the energy footprint over the life of a building by 2/3. It can also be crushed and recycled as an aggregate or material for use in road construction at the end of the building's life or as a raw material in cement production.

Thermal Efficiency: Examples exist today of buildings which produce more energy that they consume through maximising the benefits from concrete's thermal inertia assisted by sealing of buildings, natural ventilation, concrete louvers and using the building as a platform for renewable energy. Conventional buildings consume 200kWh/m²/year. By contrast, concrete technology, available today, enables buildings to be built that use 50kWh/m²/year.

Recycling and Deconstruction: There is an increasing trend to supplement conventional concrete recycling after demolition with a second model, whereby entire concrete elements are reused in their original form. A common technique is to leave the concrete structure in place, while modernising the inside space or façade/curtain wall of the building. This approach conserves natural resources and prevents the environmental impact from waste disposal and extraction, manufacturing and transportation of virgin materials. This approach is based on an original flexible building design which permits adaptation and change of use throughout the life of the building.



Another trend looks at deconstruction rather than demolition. In this case, complete building elements like walls or panels are reused in a different construction. A good example of successful reuse is the Mehrow Residence near Berlin. This new family housing concept reused complete walls, floor plates and ceilings from a demolished 11-storey tower block. The only significant energy cost arose from transportation of the five-tonne panels and use of a portable crane to lift them into position on site. Reuse of precast panels, completely free of charge, avoided the environmental impact associated with disposal and saved on material costs. Indeed, a recycled concrete panel house could potentially use three times less energy and can be approximately 30-40% cheaper than a similar house built on a new structural frame with virgin materials.

A relatively novel form of construction is based on concrete structures made of precast units using bolts or welded joints that are designed to be dismantled with little or no damage. In the Netherlands, where demolition is well organised and recovery levels are extremely high, special construction systems have been developed so that entire buildings can be dismantled and delivered to another site.

Policy recommendations

- Develop a norm for thermal inertia, which could be included in building codes to ensure that buildings take full advantage of this characteristic.
- Encourage life cycle energy use calculations in the selection of the most beneficial building materials for new structures.
- Consider rebuilding as an alternative to refurbishing, where applicable.

Another trend looks at deconstruction rather than demolition. In this case, complete building elements like walls or panels are reused in a different construction.

5.2 Recycling concrete



In brief:

- Crushed concrete can be used as an aggregate in concrete.
- The hardened cement fraction in concrete can be recycled to raw material for cement production.
- Crushed concrete can also be reused as a foundation or backfilling for many applications.

About 200 million tonnes of construction and demolition waste (C&DW) is generated every year in Europe.

Fortunately, at the end of its life cycle, concrete can be recycled thus reducing its environmental impact. The 'zero landfill' goal of concrete can be achieved if the structure is carefully conceived and designed, and if the building undergoes successful renovation or demolition. Recovered concrete from C&DW can be crushed and used as aggregate, mainly for road bases and sub-bases, but new concrete can also be made using a percentage of recovered crushed concrete. The hardened cement fraction from recovered concrete provides a good opportunity for recycling into the cement clinker process. For larger amounts, however, more efficient separation and treatment techniques would be required in order to produce a raw material with sufficient purity and homogeneity.

Crushed concrete is mostly used to build roads, streets, yards and parking areas, but can also be utilised as backfilling for pipe excavations, environmental constructions or foundations for buildings.²³ For these types of applications, using recycled concrete as the aggregate is particularly useful because it often has better compaction and density properties and is generally cheaper than virgin material.

A regular quality control system has been set up for crushed concrete to detect the presence of any hazardous substances or chemicals that could leach into the environment.

Challenges

In order to better recycle hardened cement fractions from crushed concrete, current separation technology must be significantly improved. This applies to the separation of the fine fractions of concrete from the hardened cement but equally to the separation of concrete from other building materials.

Policy recommendations

- Develop appropriate indicators to measure resource efficiency based on the entire life cycle so that the most environmentally and economically optimum use of recycled C&DW can always be identified.
- Revise local building codes to encourage increased levels of recycled content for different applications. The success of these codes would be linked to effective systems for materials testing and certification.
- Encourage development of building techniques that will allow easy sorting of construction and demolition waste.

²³ Source: Sustainable benefits of concrete structures, European Concrete Platform

5.3 Recarbonation

In brief:

- Due to their mineral composition, concrete structures slowly react with air and gradually re-absorb CO₂ over the life of the building.
- Recarbonation mainly takes place at the surface.
- If the structure can be deconstructed, crushed concrete should be exposed to the air to enable the full potential of recarbonation before it is used as a foundation or backfiller.

During the lifetime of a concrete structure (such as a building or road), hydrated cement contained within the concrete reacts with CO₂ in the air. Part of the CO₂ emitted during cement production is re-absorbed by the cement through carbonation, a reaction also referred to as cement recarbonation.

Concrete carbonation occurs on the surface of the concrete where it is in contact with air and moisture, and progresses through the concrete at a rate inversely proportional to its quality.

Structural concrete for both reinforced concrete buildings and civil engineering infrastructures is designed to last from 50 to over 100 years. For these types of concrete, the rate of carbonation is very low and unlikely to progress further than a few millimetres (5-20mm) over the lifetime of the structure.

At the end of their working life, reinforced concrete structures can be demolished. If the concrete is then crushed, its exposed surface area increases, also increasing the recarbonation rate. The amount of recarbonation is even greater if stockpiles of crushed concrete are left exposed to the air prior to reuse.

Studies have been conducted to analyse the recarbonation potential. They show that 5-20% of the CO₂ emitted during the cement manufacturing process is taken up during the service life cycle of concrete, and an additional 5-10% may be taken up during the secondary or recycled lifetime. This means that when proper recycling practices are applied, up to 25% of the originally emitted CO₂ can be re-absorbed.



Reduction through recarbonation has not been included in the model given that it is a downstream element.

Challenges

In order to benefit from the CO₂ trapping potential, crushed concrete should be exposed to atmospheric CO₂ for a period of several months before its reuse (e.g. as road underlay) which would require a new approach to managing construction waste.

Policy recommendations

- To understand the full potential of recarbonation, fundamental research should be supported. Furthermore, based on the outcome of research, an innovative set of policies on the treatment of crushed concrete building waste would enable recarbonation to reach its full potential.
- Ensure proper construction and demolition waste sorting and concrete recycling practices to optimise the CO₂ uptake at the end of life stage.
- Deconstruction and recycling would still be the best options, from a CO₂ efficiency point of view. However, this is not always possible. In such cases crushing and exposure to air to allow for recarbonation to happen should nevertheless be encouraged.

5.4 Sustainable construction

Cement production process to achieving the EU's objectives in terms of reducing CO₂ emissions.

In brief:

- Because of its thermal mass, concrete can make buildings inherently more energy efficient.
- Concrete roads reduce the fuel consumption of vehicles, especially trucks.
- High durability makes concrete a key material for sustainable construction.

Concrete as the cornerstone of sustainable construction

The opportunity for reducing emissions is not limited solely to the cement production process, but is relevant to the whole life cycle of downstream products, namely concrete. In fact, concrete can contribute much more than the cement production process to achieving the EU's objectives in terms of reducing CO₂ emissions. Energy consumption of buildings is one of today's major environmental concerns, as buildings account for approximately 35% of total EU greenhouse gas emissions²⁴ (including direct and indirect emissions from electricity generation). As concrete construction offers a higher energy-saving potential than other construction materials, it can become a key lever in achieving the EU's ambitious carbon-reduction goals, through the construction of very low-energy buildings.

²⁴European Environment Agency

Concrete buildings can achieve considerable energy savings during their lifetime because of the high level of thermal mass they deliver, meaning that the indoor temperature remains stable even when there are fluctuations in temperature outside. Concrete performs very well when accurate and holistic comparisons are made with other building materials. In the energy efficiency field, for example, energy savings of concrete structures (5-15%) in the in-use/operational phase easily offset amounts of energy consumed in their manufacture and installation phases (4-5%). Given that currently 88-98% of total building life cycle emissions are linked to the in-use phase, the savings potential offered by concrete buildings during their lifetime can totally offset initial emissions resulting from the production of cement.

In addition to its inherent thermal mass properties, concrete also facilitates the installation of enhanced cooling systems, such as radiant cooling schemes with chilled-water pipes embedded in concrete structures. Concrete delivers improved air tightness and allows enhanced installation of ventilation systems and shading structures that minimise solar gains and maximise the amount of hot or cold air coming into contact with the material.

Concrete also has a high albedo, or reflection coefficient, compared to asphalt, due to its lighter colour. This means it can reduce the need for street lighting and also reduce the heat island effect in built-up areas.

By combining all of the above, the thermal mass potential of concrete can be maximised, giving it a strong advantage over other materials and enabling construction of low-energy concrete structures that reduce energy usage from an average of 200-150kWh/m² to 50kWh/m², or even zero-emission buildings.²⁵

In the transport sector, which accounts for 20% of total European greenhouse gas emissions, concrete also contributes to reducing CO₂ emissions in a cost-effective way. According to studies, concrete pavements can lower fuel consumption of heavy trucks by up to 6% by reducing rolling resistance between the road and the truck, as concrete pavements offer a smoother surface with fewer undulations than asphalt pavements. Further reductions in fuel consumption can also be achieved through a decreased need for maintenance and, therefore, lower traffic congestion. Concrete also has a high albedo, or reflection coefficient, compared to asphalt, due to its lighter colour. This means it can reduce the need for street lighting and also reduce the heat island effect in built-up areas. Furthermore, the total life cycle costs of concrete are lower than those of asphalt. A study published by the Highway Administration of Belgium's Walloon Region concluded that concrete structures become more cost-advantageous than bituminous structures as of the 7th year following construction, out of a lifetime of more than 30 years.



Policy recommendations

- There is a need to place a strong emphasis on investments in the construction sector which is a generator of growth and jobs and, therefore, essential to economic recovery in Europe.
- Develop financing schemes to encourage individual homeowners to improve the energy efficiency of their homes through renovation or rebuilding.
- Policies need to be based on building performance and take into account impacts over the complete life cycle. Public procurement policy can lead the way in this.
- Always consider rebuilding as an alternative to refurbishing, where applicable.
- Sustainability assessment must be at the building level and take into account impacts over the complete life cycle.
- Policies such as urban planning, public procurement etc. must take a long-term view in order to encourage the most sustainable solutions.
- Encourage energy efficiency improvement of the current building stock, for example by providing financial incentives for individual home-owners for renovation or rebuilding.

²⁵ Energy Efficiency in Buildings, April 2009, WBCSD; Qualité environnementale des bâtiments, BBC, October 2009, Infociments

Towards the future





Mr Koen Coppenholle
Chief Executive of CEMBUREAU


As a society, we face a series of daunting challenges: slow or no economic growth, urbanisation, climate change, rising cost of energy... to name but a few. As corporate citizens, we share the responsibility of rising to these challenges and finding solutions, whilst doing all we can to reduce the impact of our industry on the environment.

Cement and concrete will be pivotal to addressing many of today's critical issues through sustainable building and infrastructure development. But this has to go hand in hand with concerted efforts to reduce our emissions. We support the idea of an 80% emission reduction target by 2050 and are committed to doing our part in contributing to reaching this goal. Our industry already helps current energy efficiency targets of low-carbon and low-energy life cycle consumption in the building sector to be met by providing key materials to construct very low- or even zero-energy buildings.

As the newly appointed Chief Executive of CEMBUREAU, I have found the process of developing this roadmap fascinating. It has brought out the best in our industry and has gathered many different people, from inside the industry and beyond, together with a common purpose.

The cement and concrete industry can help Europe achieve its strategic objectives on growth, innovation, social inclusion and climate and energy.

This roadmap is the result of open discussion within the industry and with external stakeholders. In the course of its development, NGOs, policymakers and international agencies were invited to provide input at various stages. The solutions outlined here are tangible and not just pipe dreams. Some of the technologies described might still be at an early development stage, but they are more than abstract ideas. Unfortunately, there is no 'silver bullet'. A combination of process efficiency, raw material choices, sustainable fuel sources, continuous innovation and breakthrough technology will all contribute to the accomplishment of our objectives.



We believe that by combining our forces, we can build a strong European industrial base within the framework of a coherent industrial policy that will deliver on all three pillars of sustainability.

The cement and concrete industry can play a crucial role in helping Europe achieve its goals, since its vision sits well with European requirements and strategic objectives on employment, innovation, education, social inclusion and climate & energy.

However, we cannot do it alone.

We are part of Europe's industrial landscape and depend on other industries, governments and players to be able to deliver on specific parts of this roadmap. For instance, using clinker substitutes will only work if we have access to a steady supply of by-products. Another example is CCS, which is a key element of this roadmap, but will require acceptance, policies and infrastructure to move it beyond the pilot phase.

Cement is still a local product, made in plants that are often the economic backbone of smaller communities, so production and innovation are often on a local scale. But Europe is at the forefront of cement and concrete innovation, and research centres across the continent are working on perfecting performance and reducing the environmental impact of products and manufacturing processes, expressly adapted to

Europe's needs. Nevertheless, cement remains a fairly standard commodity and local production, especially in areas near ports, is vulnerable to imports from countries with lower production costs or less demanding environmental requirements.

We believe that by combining our forces, we can build a strong European industrial base within the framework of a coherent industrial policy that will deliver on all three pillars of sustainability. Ensuring a competitive industry whereby access to affordable energy and raw materials and predictability of legislation are given appropriate attention is a precondition for the survival of the cement industry in Europe and its contribution to growth, innovation and employment. We hope that this roadmap will form the basis for continued dialogue with a wide range of stakeholders, both inside and outside the industry, and offer further perspectives on how we can work together on building a low-carbon society.

Mr Koen Coppenholle
Chief Executive of CEMBUREAU

ANNEX 1:

European Standards for Cement and Concrete

Cement

European cement standard EN 197-1 Cement – Part 1: Composition, specifications and conformity criteria for common cements defines 27 distinct common cement products and their constituents. The standard includes requirements for constituents and performance requirements in terms of mechanical, physical and chemical parameters for all 27 products.

Three standard strength classes are defined at 28 days (32.5, 42.5 and 52.5). In addition, three early strength classes are included for each standard strength class: low early strength, ordinary early strength and high early strength.

The 27 products are grouped into five main cement types as follows:

- CEM I Portland cement (>95% clinker)
- CEM II Portland-composite cement (65-94% clinker)
- CEM III Blastfurnace cement (5-64% clinker)
- CEM IV Pozzolanic cement (45-89% clinker)
- CEM V Composite cement (20-64% clinker)

Concrete

European concrete standard EN 206-1 Concrete – Part 1: Specification, performance, production and conformity applies to concrete for structures cast in situ, precast structures, and precast structural products for buildings and civil engineering construction. The concrete may be mixed on site, ready-mixed or produced in a plant for precast concrete products.

The standard specifies requirements for the following:

- Constituent materials of concrete
- Properties of fresh and hardened concrete
- Limitations for concrete composition

EN 206-1 is a voluntary rather than harmonised standard. Where general solutions have not been agreed across Europe, relevant clauses permit the application of national standards or provisions valid where the concrete is used. CEN members, through their national application of EN 206-1, outline, in a national annex, rules based on historical experience for the use of cements in concrete for specific applications. In many cases, these rules also extend to the use of various additional cement constituents (inorganic materials) deemed appropriate for such applications.

Varying climatic conditions, raw material availability and experience have led to significant differences in standards, regulations and practices in local and regional markets in terms of how different cement types can be used for given applications. This is due to historical knowledge of cement performance in its numerous applications and the diversity of climatic conditions found across Europe.

ANNEX 2:

Sustainable Cement Production

Co-processing of alternative fuels and raw materials

Cement plants are an essential part of Europe's industrial landscape and are increasingly important partners in innovative waste management solutions, called co-processing. Co-processing waste in this way consists of using both the calorific potential to heat the kiln and the material component from the fuel ash as a raw material, thereby reducing our requirement for natural resources.

Many different types of industrial by-products, waste and biomass can be used as fuel in a cement

kiln, including refused derived fuel, waste oil, waste wood, sewage sludge, waste tyres, plastics, bone meal, solvents and impregnated sawdust. Once the calorific potential of this waste has been recovered, what is left over (i.e. ashes) will be bound in the clinker during the burning process, and thus used as a raw material to produce cement. This cannot be done in an arbitrary way however, as the chemical composition of the fuel ash must fit the overall raw meal composition. Therefore a good knowledge of the calorific and chemical composition of any fuel used in cement production is mandatory.

Win-win-win

The use of waste materials and by-products offers a win-win-win situation. The cement sector helps other industries or municipalities dispose of their waste and, in exchange, gains access to cost-effective fuel sources or raw materials. Moreover, co-processing decreases dependency on fossil fuels, reduces the need for quarrying, and prevents waste ending up in landfill. It also has a direct impact on lowering CO₂ emissions, since it reduces the quantity of natural raw materials needed for clinker production.

Co-processing in Europe varies from country to country because of different national regulations and/or waste management practices or local markets specificities. Acceptance by local authorities and communities or the vested interests of other economic actors can reduce the uptake of waste materials by the cement industry. Use of alternative resources in certain European countries is low and there is a clear potential for increased co-processing to benefit the environment, industry and society.

Principles of co-processing at a glance

Co-processing offers a solution to use both waste and industrial by-products in a way that maximises their potential, i.e. by extracting the energy potential and using what remains as a raw material.

Co-processing is effective because it is based on sound principles.

Co-processing respects the waste hierarchy:

- Co-processing does not hamper waste reduction efforts.
- Co-processing does not replace recovery nor recycling but is a waste management solution that can reduce the amount of waste that is landfilled or incinerated without energy and material recovery.
- Co-processing is regarded as a flexible and integral part of modern waste management, as it provides an environmentally sound resource recovery option.

- Co-processing must remain in line with relevant international environmental agreements.²⁶

Controlled emissions and no health effects:

- Due to the inherent features of cement kilns, i.e. high temperatures, stable operation, long residence time and high volumes of alkali raw materials, co-processing is a safe waste recovery option.
- Emissions from cement kilns using alternative fuels can be lower than those from cement kilns with traditional fuels.
- Co-processing has even proven very useful in specific cases, such as safe utilisation of meat and bone meal in Europe.

Cement and concrete quality remains unchanged:

- Product quality (clinker, cement, concrete) must remain controlled and fully within standards.
- Concrete must fulfil environmental norms e.g. leaching tests, enabling it to be used for uses including water reticulation.
- The quality of cement should allow end-of-life recovery.

Companies engaged in co-processing must be qualified and able to:

- Show good environmental and safety compliance track records and provide relevant information to the public and appropriate authorities.
- Ensure adequate personnel, processes and systems to demonstrate commitment to the protection of the environment, health and safety.
- Ensure all activities comply with applicable laws, rules and regulations.
- Control inputs and process parameters required for effective co-processing of waste materials.
- Maintain good relations with the public and other stakeholders in local, national and international waste management schemes.

Implementation of co-processing has to consider national circumstances:

- Country-specific requirements and needs must be reflected in regulations, procedures and implementation.

- Stepwise implementation will allow for the build-up of required capacity and set-up of institutional arrangements.²⁷
- Countries can maximise the use of waste materials for alternative fuels to avoid the depletion of local fossil fuels and/or to minimise the need to import fuels, thereby reducing national energy costs as well as the emissions associated with transportation.
- Co-processing has to take into account specific national circumstances. However, country-specific requirements, should ideally aim to be as homogeneous as possible at EU level, in order to avoid different treatments between countries.

Substituting clinker with other suitable materials

Part of the clinker used in certain types of cement can be replaced with alternative materials. Two main examples are granulated blastfurnace slag, a by-product of the steel manufacturing process, and fly ash, one of the materials resulting from the combustion of coal in traditional coal fired power plants.

The use of these by-products in cement production is not new; it has been common practice for decades and has led to several innovative cement types sometimes with different and beneficial characteristics. By using these products in cement manufacturing, millions of tonnes of alternative raw materials are put to good use, do not end up in landfill sites, reduce the need for virgin raw materials and lower the CO₂ content of the resulting cement.

In numbers

Cement manufacturing is a volume business and the volumes of waste and by-products used are important. In 2010, the European cement industry recovered or recycled:

- Over 13 million tonnes of granulated blastfurnace slag;
- Close to 5 million tonnes of fly ash;
- Over 7 million tonnes of waste materials such as tyres, sewage sludge, saw dust.

Using waste or industrial by-products in cement plants also makes sense from a financial point of view for local or regional governments because these materials are recovered using existing infrastructure without the cost of building an incinerator.

²⁶ Namely the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal and the Stockholm Convention on Persistent Organic Pollutants.

²⁷ Source: Guidelines on Co-processing Waste Materials in Cement Production, The GTZ-Holcim Public Private Partnership

Rue d'Arlon 55, BE-1040 Brussels

Tel: +32 2 234 10 11 | Fax: +32 2 230 47 20

www.cembureau.eu

The full Roadmap is available at:

lowcarboneyconomy.cembureau.eu



THE EUROPEAN
CEMENT ASSOCIATION

Comments on this roadmap are welcome and should be sent to
Jessica Johnson (aj.johnson@cembureau.eu)