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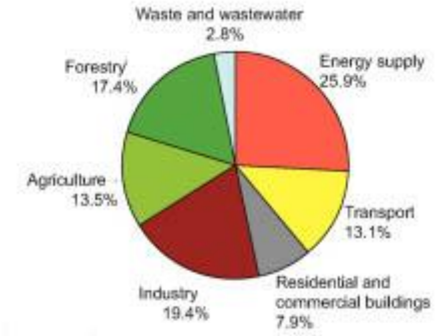
Global Warming & Contribution of CO_2 from Cement Industries.

Global warming is primarily a problem of too much carbon dioxide (CO2) in the atmosphere—which acts as a blanket, trapping heat and warming the planet. As we burn fossil fuels like coal, oil and natural gas for energy or cut down and burn forests to create pastures and plantations, carbon accumulates and overloads our atmosphere. Certain waste management and agricultural practices aggravate the problem by releasing other potent global warming gases, such as methane and nitrous oxide. See the pie chart for a breakdown of heat-trapping global warming emissions by economic sector.



CO2 survives in the atmosphere for a long time—up to many centuries—so its heat-trapping effects are compounded over time. Of the many heat-trapping gases, CO2 puts us at the greatest risk of irreversible changes if it continues to accumulate unabated in the atmosphere. Substantial scientific evidence indicates that an increase in the global average temperature of more than 3.6 degrees Fahrenheit (°F) (or 2 degrees Celsius [°C]) above pre-industrial levels poses severe risks to natural systems and to human health and well-being.
Delayed action is also likely to make it more difficult and costly to not only make these reductions, over the last century; global average temperature has increased by more than 1°F (0.7°C). In fact, nine of the warmest years on record have occurred in just the last 10 years. This warming has been accompanied by a decrease in very cold days and nights and an increase in extremely hot days and warm nights.
Of course, land and ocean temperature is only one way to measure the effects of climate change. A warming world also has the potential to change rainfall and snow patterns, increase droughts and severe storms, reduce lake ice cover, melt glaciers, increase sea levels, and change plant and animal behavior.

Need to Improve production methods that reduce or eliminate CO2emissions from the cement manufacturing process

Globally, over 150 countries produce cement and/or clinker, the primary input to cement. Cement is often considered a key industry for a number of reasons. To begin with, cement is an essential input into the production of concrete, a primary building material for the construction industry. Due to the importance of cement for various construction-related activities such as highways, residential and commercial buildings, tunnels and dams, production trends tend to reflect general economic activity. Furthermore, because of the large demand for cement, the relatively high costs associated with transport of the high-density product, and the wide geographic distribution of limestone, the principal raw material used to produce cement, cement is produced across the United States.

Annually, the United States submits a national inventory of GHG emissions to the United Nations Framework Convention on Climate Change (hereafter referred to as the Inventory). Emission estimates included in the Inventory are based on methodologies developed by the IPCC, as well as some country-specific methodologies consistent with the IPCC. The Inventory estimates U.S. process-related emissions from cement production to be 41.4 TgCO2 in 2018. Due to the nature of the IPCC Guidelines, as well as the way industrial sector emissions are estimated in the United States, combustion-related emissions resulting from the cement industry are not as well characterized. While combustion-related emissions from cement production are incorporated into the Inventory, they are aggregated and presented in the estimate of CO2 emissions from fossil fuel combustion.

Due to the very high temperatures reached in cement kilns a large variety of fuel sources can be used to provide energy. Coal is responsible for the largest share of energy consumption at cement kilns, approximately 71%. Approximately 12% of energy consumption is derived from petroleum coke, 9% from liquid and solid waste fuels, 4% from natural gas, and the remainder from oil and coke15.

The cement industry is becoming increasingly concentrated, with a few multinational cement companies assuming ownership of increasing shares of cement manufacturing plants.

The cement industry faces a number of challenges that include depleting fossil fuel reserves, scarcity of raw materials, perpetually increasing demand for cements and concretes, growing environmental concerns linked to climate change and an ailing world economy.

OPC is a vital construction material and also a strategic commodity. Such is our dependence on OPC that the world currently produces nearly 3.6 billion metric tonnes of the material each year as per USGS Mineral Commodities, with volume predicted to rise to more than 5 billion metric tonnes by 2030. Although figures vary from country to country, around half of the world's OPC is used to make around 11 billion metric tonnes of concrete annually; the rest is used in mortars, screeds, stucco, coatings, soil stabilization and other applications.

Today, the OPC market is dominated by China, which is attributed to 57.3% of global consumption .The cement industry, like the rest of the construction industry, is facing unprecedented challenges relating to energy resources, CO2 emissions and the use of alternative materials. Worldwide, the cost of energy is rising inexorably as fuel sources deplete. This has clear, traceable impacts on the cost of producing cement and its market price; Green taxes are an additional cost that is incurred if emissions are not restricted, potentially leading to a doubling in the price of cement by 2030.

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Cement Manufacturing Process

Cement was founded over a hundred years ago and is a privately owned independent trade magazine dealing with the problems of production and application of cement in Russia and in other countries of the world. Great attention is paid to the problems of cement plants development, capital flow and economic issues of Russian and international industry.

The following are the types of cement that are in practice:

Types of Cement	Composition	Purpose
Rapid Hardening Cement	Increased Lime content	Attains high strength in early days it is used in concrete where form work are removed at an early stage.
Quick setting cement	Small percentage of aluminium sulphate as an accelerator and reducing percentage of Gypsum with fine grinding	Used in works is to be completed in very short period and concreting in static and running water
Low Heat Cement	Manufactured by reducing tri-calcium aluminate	It is used in massive concrete construction like gravity dams
Sulphates resisting Cement	It is prepared by maintaining the percentage of tricalcium aluminate below 6% which increases power against sulphates	It is used in construction exposed to severe sulphate action by water and soil in places like canals linings, culverts, retaining walls, siphons etc.,
Blast Furnace Slag Cement	It is obtained by grinding the clinkers with about 60% slag and resembles more or less in properties of Portland cement	It can used for works economic considerations is predominant.
High Alumina Cement	It is obtained by melting mixture of bauxite and lime and grinding with the clinker it is rapid hardening cement with initial and final setting time of about 3.5 and 5 hours respectively	It is used in works where concrete is subjected to high temperatures, frost, and acidic action.
White Cement	It is prepared from raw materials free from Iron oxide.	It is more costly and is used for architectural purposes such as pre-cast curtain wall and facing panels, terrazzo surface etc.,
Coloured cement	It is produced by mixing mineral pigments with ordinary cement.	They are widely used for decorative works in floors
Pozzolanic Cement	It is prepared by grindin	It is used in marine structures, sewage

	pozzolanic clinker with Portland cement	works, sewage works and for laying concrete under water such as bridges, piers, dams etc.,
Air Entraining Cement	It is produced by adding indigenous air entraining agents such as resins, glues, sodium salts of Sulphates etc during the grinding of clinker.	This type of cement is specially suited to improve the workability with smaller water cement ratio and to improve frost resistance of concrete.
Hydrographic cement	It is prepared by mixing water repelling chemicals	This cement has high workability and strength

Recent trends and developments in cement industry

The cement industry faces a number of challenges that include depleting fossil fuel reserves, scarcity of raw materials, perpetually increasing demand for cements and concretes, growing environmental concerns linked to climate change and an ailing world economy. Every tonne of Ordinary Portland Cement (OPC) that is produced releases on average a similar amount of CO2 into the atmosphere, or in total roughly 6% of all man-made carbon emissions. Improved production methods and formulations that reduce or eliminate CO2emissions from the cement manufacturing process are thus high on the agenda.

Uses of Petroleum Coke

Petroleum coke (pet coke) is one of many valued consumer products produced during the oil refining process. Crude oil is processed into gasoline, diesel fuel, jet fuel, lubricating oils and waxes, leaving some residual crude that usually undergoes additional processing. The crude residue may be further refined by a process known as coking to produce transportation fuels as well as pet coke.

Petroleum coke is typically used as a source of energy, or as a source of carbon for industrial applications. Fuel grade pet coke represents nearly 80 percent of worldwide production and is a source of fuel for cement kilns and electric power plants. Calcined pet coke has the highest carbon purity and is used to manufacture energy, as well as in the aluminum, graphite electrode, steel, titanium dioxide and other carbon consuming industries.

Health and Environmental Impacts of Petroleum Coke

According to the Congressional Research Service (CRS), “The Environmental Protection Agency (EPA) does not classify pet coke as a hazardous waste. EPA has surveyed the potential human health and environmental impacts of pet coke through its High Production Volume (HPV) Challenge Program and found the material to be highly stable and non-reactive at ambient environmental conditions. Most toxicity analyses of pet coke find it has a low potential to cause adverse effects on aquatic or terrestrial environments as well as a low health hazard potential in humans, with no observed carcinogenic, reproductive, or developmental effects.”

Despite the incremental improvements in process efficiency that have been adopted by the cement industry in recent years, OPC production is still responsible for around 6% of all man-made global carbon emissions. The *Cement Sustainability Initiative*, developed by the World Business Council for Sustainable Development, brings together the major cement producers from across the world to try and tackle this problem An important part of the initiative is a database showing CO_2 emissions and energy performance figures for many of the significant players in the global cement industry, to promote the sharing of ideas aimed at improving these values.

The push to reduce global CO_2 emissions is backed by governments and corporations who understand that the present rate of release of this greenhouse gas into the atmosphere is a serious threat to future life and prosperity on the planet. Various authorities have introduced legislation and incentives (tax rises such as CO_2 taxes, quarrying and extraction tax, etc.) in order to regulate and reduce the activities of the industrial sectors most responsible for greenhouse gas emissions.

However, the rate of increase in emissions continues almost unabated as a result of population growth and increased industrialization and economic activity in developing countries, notably in Latin America, Africa, the Middle East, India and developing countries in Asia where a three to fourfold increase in demand is projected by 2050.

If the cement and concrete industries are to become sustainable and effectively contribute to emission reduction then, in addition to improvements in process efficiency and reliance on OPC blends incorporating waste materials, moving to less carbon intensive fuels, developing clinker substitutions employing other low carbon materials with cementitious properties and new low carbon and carbon-reducing cement formulations and production processes are needed.

Carbon-reducing cements, if they could be developed for commercial-scale application, probably offer the safest, most economical and elegant Carbon Capture and Storage (CCS) technology. Other approaches to CCS that requires piping CO_2 emissions from cement production (and other polluting sources such as power generation), is viewed by some as the best way forward. However, widespread concerns relating to long-term reliability and high capital cost suggest that ideas such as pressurized, pumped storage of liquefied CO_2in geological formations may be neither technically nor commercially viable. They cannot be relied on to provide a permanent solution as the risk of containment failure is simply too great.

In order to appeal to major cement manufacturing companies, an alternative cement product has to be able to generate at least the same economic value as that from an OPC production plant. At 7.6% of world cement production, the cement industry in Europe represents around 56,000 direct jobs. The average cement plant will produce around 1 million tonnes of cement per annum and cost around €150 million. Advances in automation mean that a modern plant is usually manned by less than 150 people

Each tonne of OPC produced requires 60–130 kg of fuel oil or equivalent, depending on the cement variety and the process used, and about 110 KWh of electricity. This accounts for around 40% of the average 0.9 tonnes of CO_2 emissions per tonne of cement produced, with the rest attributed to the calcinations process, other manufacturing processes and transportation.

Concretes, on the other hand, refer to mixtures comprising coarse aggregates (such as crushed rock, ranging in size from 5 to 20 mm), fine aggregates (such as sand, ranging in diameter from 63 microns to 5 mm) and a cement binder. When mixed with appropriate quantities of water and (where required) performance-enhancing admixtures, this produces an initial fluid phase that can be shaped or cast and sets to produce a solid phase comprising a very strong, rigid concrete element or structure.

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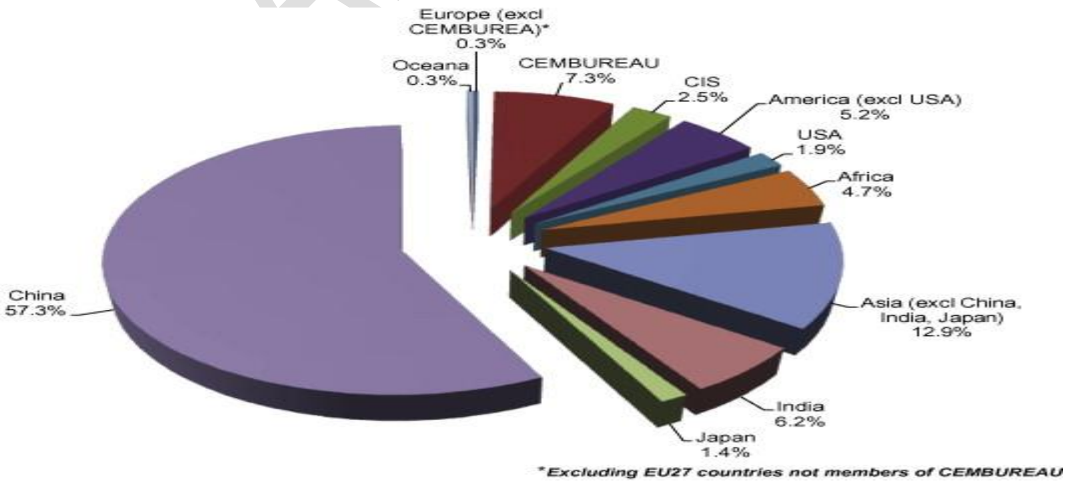
As alternative low-carbon cements and concretes enter the equation, three conditions will determine their success or otherwise;
firstly that they are useable and perform well both short term and long term,
secondly that there is sufficient information validating the capabilities of the product so that they meet engineering standards for specific functions, ranging from the making of cavity blocks to ready-mix for in situ casting of foundations,
Thirdly, that there is sufficient raw material that can be transported in bulk to processing plants.
Although the ingredients for making cement are readily available in most countries, there may be opportunities to use locally sourced specific raw materials such as industrial waste, recyclable material or even earth.
These materials must of course have controlled characteristics and properties that are suitable for purpose, whether it is for blending ground granulated blast furnace slag for strength enhancement or soil for producing compacted earth blocks.
The present topic examines the production of OPC (the benchmark cement against which all cements is measured) and applicable standards. It will summarize the waste substitutes that are currently being used to reduce the carbon footprint of a range of Portland-based cements. Co-incineration of waste-derived fuels (municipal waste, sewage sludge, animal meal, waste by-products, etc.), to reduce emissions and effectively dispose of these wastes, will also be briefly discussed. Some traditional replacement cements will be the emerging, next generation of green alternative cements such as Calcium Sulfoaluminate (C$A) cement, successfully developed and used in China will be introduced.

World Portland cement production

A review of recent trends in the global production of cement shows that the estimated amount of cement produced over the world was 3.6 billion tonnes – see the Pie chart, which shows that China dominates most of the market followed by Asia Typical cement plant capacity is expected to remain in the range of 1.5 and 2.5 million tonnes per annum.



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World Portland cement production today.

Above Figure shows global cement production increasing constantly from 1990 to 2050. This is to be expected as it is the second most consumed product on the planet after water. The industry is growing particularly rapidly in developing countries such as India and China that have a high demand for infrastructure and housing

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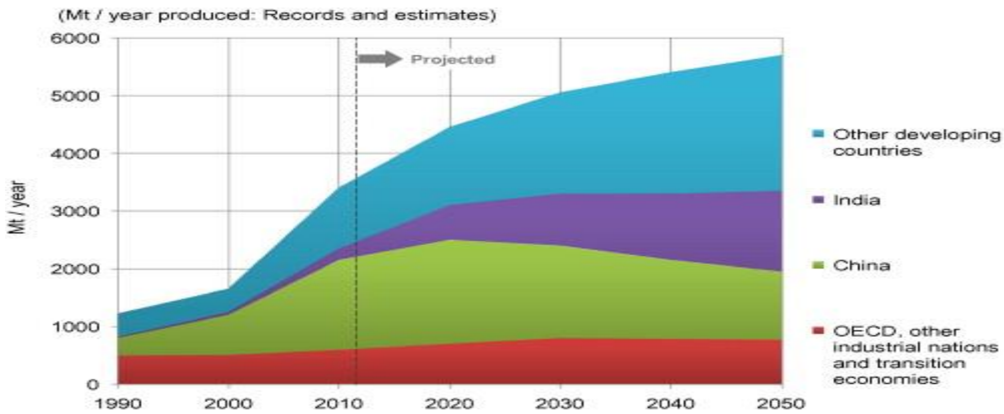

World Portland cement production 1990–2050.

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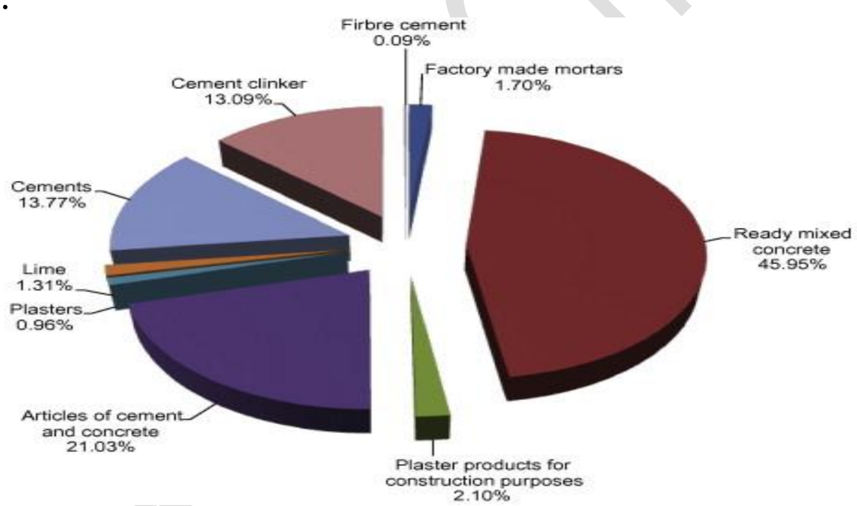

Cement, concrete and plaster products in the UK construction market.

Current energy use and CO_2 emissions

Approximately 3.6 billion tons of cement is produced globally every year. A conservative estimate for every 1 kg of cement produced gives a by-product of 0.9 kg of carbon dioxide this

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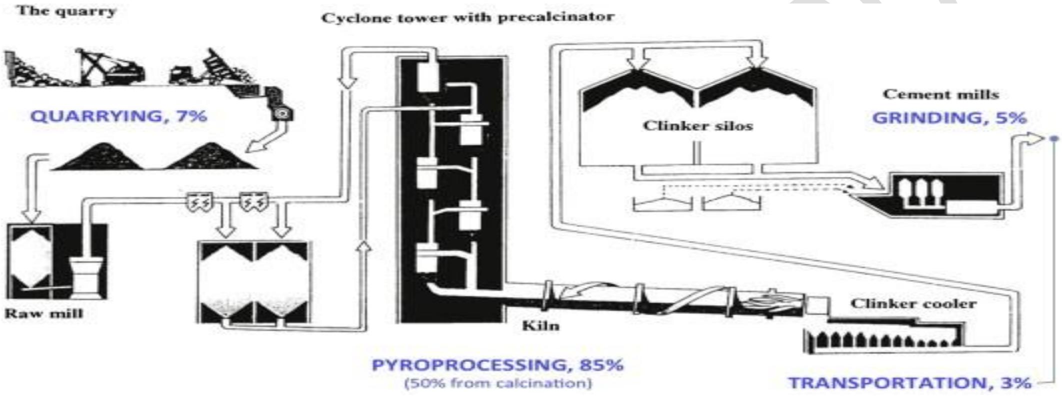
equates to 3.24 billion tonnes of CO2 per year. These figures do not include CO2 and other green house gasses emitted during the quarrying and transport of raw materials or the loading, unloading and transportation of the cement produced.

The main sources of emissions in the OPC manufacturing process are in two parts:
From the calcination process as described earlier.
From the combustion fuel used to heat the raw materials to sintering temperatures (1400–1600 °C). The amount of CO2 emission depends on the type of fuel and the particular processing method used.
Kilns are fired using coal, fuel oil, natural gas, petroleum coke, biomass, waste-derived alternative fuels or mixtures of these fuels. The theoretical heat requirement for clinker-making is calculated to be about 1.75 ± 0.1 MJ per kg; however; process inefficiencies mean the actual heat requirements are higher.
The production process is diagrammatically shown and the key stages are described in the rest of the section.



Share of total CO_2 emissions across the Portland cement production process.

Quarrying

The raw materials are milled together to achieve the right composition before being sent to the kiln for pyroprocessing. Only the operation of machinery is responsible for CO2emissions when quarrying for raw materials.

Pyroprocessing

Cement clinker is made in a rotary kiln, or long cylindrical rotary furnace that turns around once or twice every minute. Temperatures are generally around 1400–1600 °C, and energy demand varies depending on the manufacturing process. The material undergoes the process known as calcinations inside the kiln after all moisture is evaporated out, about a third of the way down the kiln. The end product size ranges from dust to big lumps of calcium silicate or clinker.

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Note the below table for CO_2 emissions in kg per kg cement produced for various fuels and various clinker/cement ratios (Assumptions)

Electricity use is 0.38 MJe/kg of clinker; the average emission factor of CO_2 of electricity production is 0.22 kg/MJe;

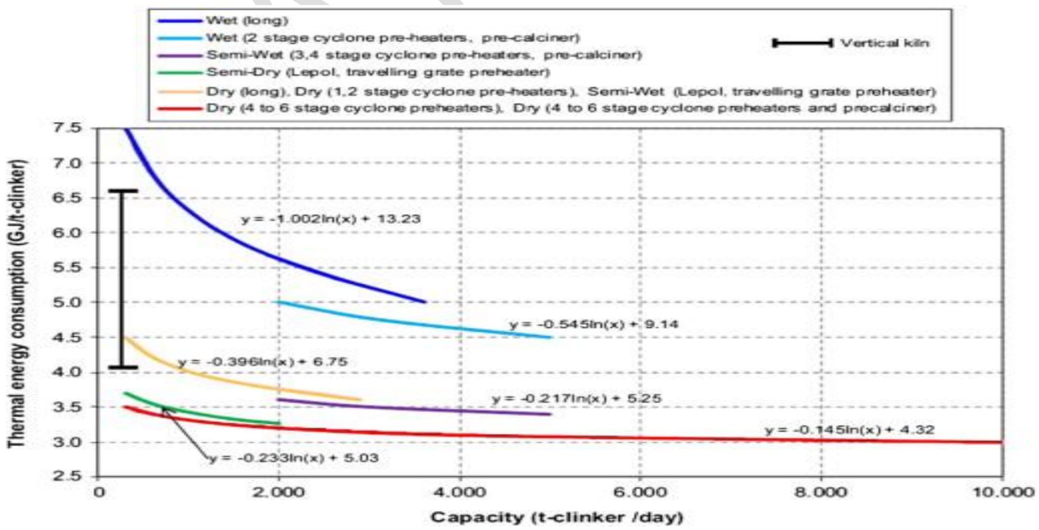
fuel use is 3.35 MJ/kg of clinker (dry process)

5.4 MJ/kg of clinker (wet process).
[It should be noted these figures assume that no CO_2 penalty is attached to materials such as slag or fly ash and some may argue they are therefore highly artificial, erring on the optimistic.]

CO_2 emissions in kg per kg cement produced for dry and wet cement production process for various fuels and various clinker ratios.

Clinker ratio[a] (%)	Calcination process	Dry kiln process				Wet kiln process			
		Coal	Oil	Gas	Waste	Coal	Oil	Gas	Waste
55	0.28	0.55	0.50	0.47	0.36	0.67	0.59	0.53	0.36
75	0.38	0.72	0.66	0.61	0.47	0.88	0.77	0.69	0.47
(Portland) 95	0.49	0.89	0.81	0.75	0.57	1.09	0.95	0.90	0.57

The following chart indicates the spans a range of thermal energy efficiencies in Portland cement clinker production, from lowest to highest energy consumptions based on type and capacity of kiln.



Energy efficiency in clinker production

Grinding

The lumps of clinker are ground up with calcium sulfate dihydrate ($CaSO_4 \cdot 2H_2O$) or gypsum or active anhydrite to control the rate of hardening or the setting time Usually about 2–10% of the ground-up Portland cement is gypsum. The final product, OPC cement is used in various ways, primarily to make mortar and concrete, cinder or cavity block.

Transportation

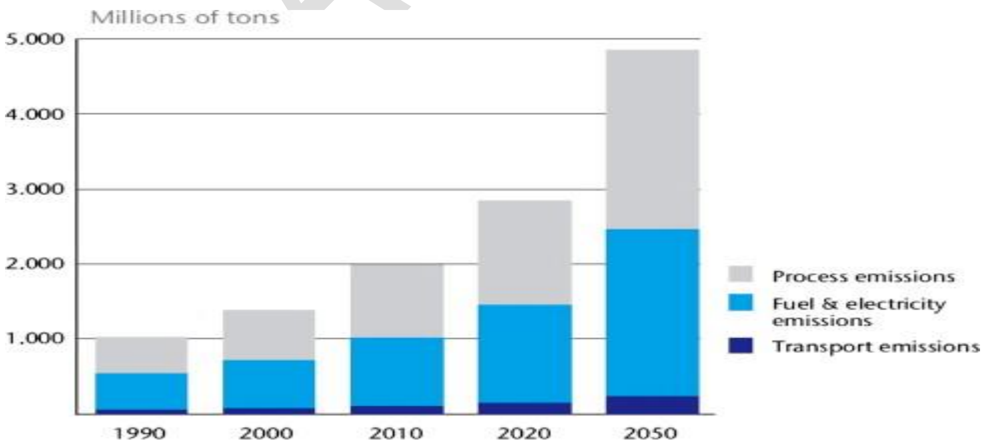
The cost of transporting bulk commodities greatly affects cement production. Barge and rail modes account for the remaining distribution. Exported cement is invariably transported by land or sea. The estimated emission rates of transport by truck, rail and ship are, respectively 0.033, 0.017 and 0.010 $kgCO_2$/tonne-kilometer.

Future CO_2 emissions effect

The Cement Sustainability Initiative recommends how the industry can make changes on a global scale by promoting the best available efficiency technologies for new and existing production plants, increasing awareness of alternative fuels and encouraging clinker substitution.

Recommendations also include initiation of government support programmes that will help fund new industry pilot projects. The below chart indicates the projected CO_2emissions from the cement industry if no changes are made to current production methods.

By 2050 the emissions will have increased by almost 5 times the value in 1990. This is not a good path to be on when the world is becoming more green-aware. These initiatives will thus not only help pave the way for a ‘greener’ cement industry but will also be beneficial in reducing greenhouse gas taxes and ensuring the continuation of the industry in an economic climate of ever increasing costs.



Projected global cement industry reference CO2, million metric tonnes

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The predictions were made in the year 2000 and suggest CO_2 emissions rising from around 1.4 billion to just under 2 billion tonnes of CO_2 per year in 2010 and 4.8 billion tonnes of CO_2 per year in 2050.
The CO_2 emission today is 3.24 billion tonnes of CO_2 per year. The original predictions have therefore underestimated the increase in CO_2 emissions by 124% – i.e., 2.24 billion as opposed to 1 billion tonnes CO_2 per year.

Novel, resource efficient cements

To improve energy efficiency and reduce carbon emissions, the approaches that have been adopted can be summarized under the following four main headings:

Manufacturing processes in cement production have been and continue to be optimized and automated, using the best technologies available to reduce cost, emissions and increase productivity. This has led to incremental reductions in Green House Gas (GHG) emissions and has also reduced the industry's employment levels.
Co-incineration of waste fuels such as plastics from demolition activities, wood, rubber tires, industrial and municipal sewage sludge, animal wastes (fats, carcasses, etc.), agricultural waste, solid waste, solvents and oils is a booming industry in some European countries, notably Germany.
The disadvantages are increased CO_2 emissions and release into the atmosphere, if not properly (and expensively) managed, of hazardous materials like sulfur dioxide (SO_2) and other sulfur compounds, total organic compounds (TOC) including volatile organic compounds (VOCs), polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD and PCDF) and metals (including Hg, Cd, As, Pb) and their compounds. With the exception of waste biomass alternative fuels, which if used can deliver a net CO_2 emission reduction; co-incineration of waste products addresses a different sustainability agenda (management of waste).
{Supplementary Cementitious Materials (SCMs) in cement production}

Novel cements involve development of cement manufacturing processes that use different raw materials. The shared aim of novel cement developers is cement that emits less $CO_2$and requires less energy to produce, without reducing or compromising the efficiency of the cement.

Alternative fuel substitutes

The firing of cement clinker kilns is traditionally fueled either by coal or petroleum coke, or, to a lesser extent, alternatively by natural gas or fuel oil. Use of other fuels such as biomass can be an effective fossil fuel substitute, producing CO_2 emissions that are about 20–25% less than those of coal.
Not only do reduced emissions make such fuels suited for cement kilns, but combustion products of inorganic compounds such as ash are also integrated into and can contribute beneficially to the clinker product.

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Silica fume

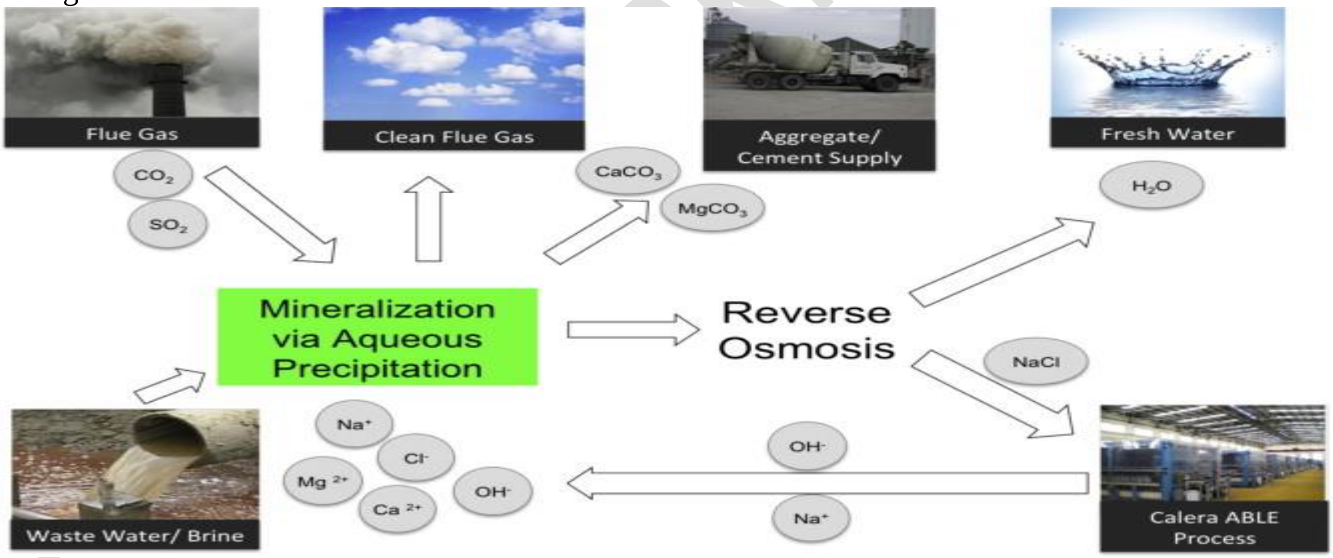
Silica fume, also known as microsilica, is a by-product of the production of silicon and silicon alloys in electric arc furnaces. It is added to cement to produce high performance concretes that are much stronger and more durable than other concretes made using blended cements; it is also very useful for reducing the permeability of concrete and therefore able to better protect steel reinforcement.

Alkali-activated cements/geopolymers

Alkali-activated cements (AACs) are competitive with ordinary Portland cement (OPC) in performance and cost, and their production emits 95% less CO2 than OPC (if the NaOH and KOH required are assumed to be carbon free); they have longer life, better durability, and they recycle millions of tons of industrial waste – i.e., Recovered Mineral Components (RMCs).

Sequestrated carbon cement

The Calera Corporation have a process that essentially mimics marine cement, similar to what is found in the coral reef, taking the calcium and magnesium in seawater and captured carbon dioxide from effluent gases to form carbonates. The idea is that CO2 rich gases are filtered through sea water.



Carbonation formation according to Calera.

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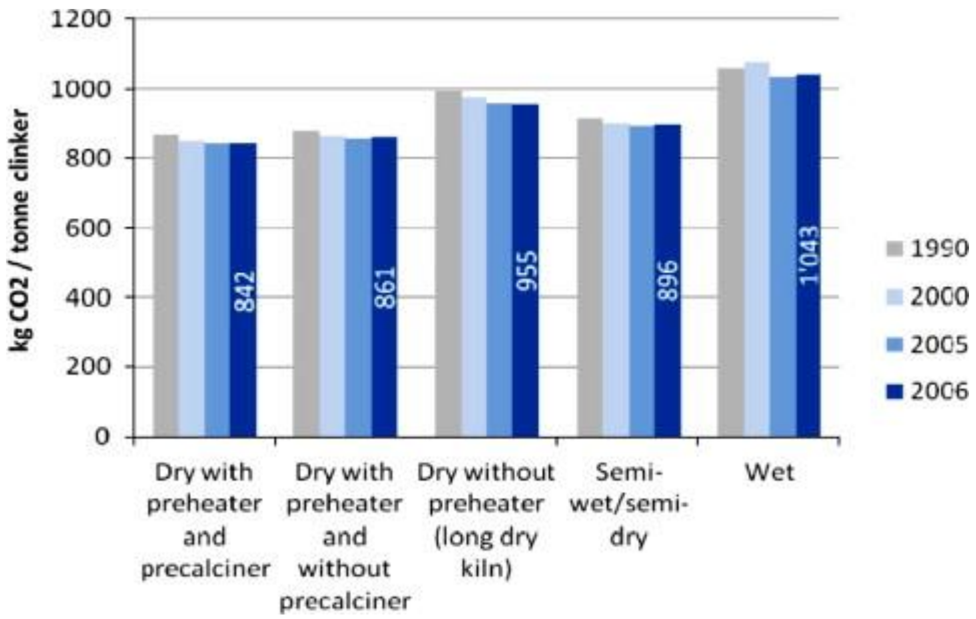
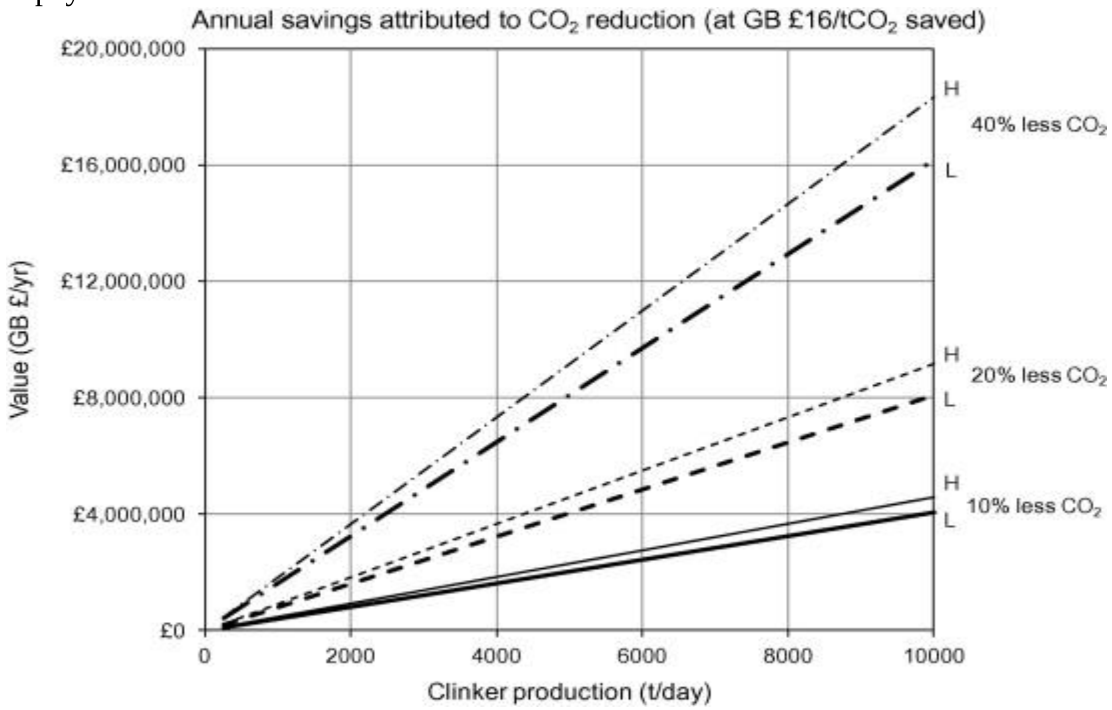


Global gross CO_2 emissions per tonne of clinker per kiln type.

to pay back the investment.



The value of carbon emission reduction in gross cement production.

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Conclusions

It is clear that cement, in all its different types and forms, is a vital product that, combined with other ingredients in the correct ratio, makes it a key construction material. Concrete is a prime example of a cement-based construction material. The demand for concrete is high, increasing and recognizes no borders. This will continue to be the case for the foreseeable future.

In order to ensure sustainable, cost-effective but still profitable cement production in the second decade of the 21st century, the industry needs to change. The two most important challenges facing the industry are a pressing need to reduce CO2 emissions and improve energy efficiency. Some of the remedies have been outlined, but more research is needed. Alternative fuels derived from waste are currently being used in some parts of the world, helping to reduce energy costs, generate income and reduce landfill, but not all alternative fuels reduce CO2 emissions. The use of other fossil fuels such as biomass, on the other hand, can be an effective fuel substitute, producing CO2 emissions that are about 20–25% less than those of coal. However, the IEA's predictions suggest that it will only be economically viable for the cement industry to use biomass sourced alternative fuels until 2030; it remains to be seen if other alternative low carbon fuels can be found or developed before then.
A large fraction of the CO_2 that is released in the production of Portland cement is from the calcinations process itself; it is a byproduct of the firing of calcium carbonate and silica in a rotary kiln to produce calcium silicate (clinker) and carbon dioxide.
Novacem's carbon-reducing cement, still in the early stages of development, perhaps held the greatest promise for entirely eliminating CO_2 emissions from cement production.
An important pre-requisite for investment in new, low carbon cement technologies, is price stability. This is the silver lining that manufacturers in Qatar and Saudi Arabia can benefit from as a consequence of government subsidies and in the US as a consequence of a combination of a Hurricane Katrina and the economic crisis.

One very important development that will affect the cement industry's future in the UK is the introduction of a carbon tax on emissions and introduction of a carbon price floor in April 2013. It is likely that other countries in Europe and worldwide will introduce similar measures aimed at carbon emission reduction.

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