Cement Technology Roadmap 2009

Carbon emissions reductions up to 2050

World Business Council for Sustainable Development

International Energy Agency

Current trends in energy supply and use cannot be sustained – economically, environmentally or for our society. We can and must change the path that we are on: this will take an energy revolution, with low-carbon energy technologies at the centre. While all the precise steps in the pathway to a low-carbon economy may not be perfectly clear, we cannot wait for this path to clarify itself. Instead we must proactively move forward with technology research, development and deployment in order to shape the future ourselves.

In 2008 G8 leaders in Hokkaido requested the International Energy Agency (IEA) to lead the development of a set of roadmaps, focusing on the most critical low-carbon technologies on both energy demand and supply. These roadmaps will help identify the necessary steps for accelerated and radical technology changes and thereby enable governments, industry and financial partners to make the right choices. This will in turn help societies make the right decisions.

Recognising the urgency of identifying technology to reduce the CO_2 intensity of cement production, the IEA has worked together with the World Business Council for Sustainable Development (WBCSD) Cement Sustainability Initiative (CSI) to develop a technology roadmap for cement. This is currently the only industry-specific roadmap; others focus on specific technologies. This joint effort shows willingness to build on progress already made, as well as the industry's understanding that further progress lies ahead.

CO_2 emissions from cement production currently represent about 5% of anthropogenic global CO_2 emissions. Since 2002, CSI member companies have collectively made significant progress on measuring, reporting and mitigating their CO_2 emissions, and sharing their progress with the rest of the cement industry. This technological roadmap is a logical and complementary next step to promote effective action against climate change. The cement roadmap outlines a possible transition path for the industry to make continued contributions towards a halving of global CO_2 emissions by 2050. As part of this contribution, this roadmap estimates that the cement industry could reduce its direct emissions 18% from current levels by 2050. A reduction of global emissions does not imply a linear reduction by the same percentage in all industries. This roadmap should be understood as a deep analysis of potentials and challenges in one industry.

The vision for such reductions is ambitious, yet the changes required must be practical, realistic and achievable. This roadmap is a first step. It is only attainable with a supportive policy framework, and appropriate financial resources invested over the long term. The roadmap outlines these policies, estimates financial requirements, and describes technical changes, along with recommendations to support research and development (R&D) and future investment decision-making.

We have developed this roadmap together to show the value of collaboration and partnership in achieving the deep emissions reductions required globally. We offer here one potential pathway for one industry. With this, we seek open dialogue with policy-makers, financial partners and other industries to help us all to adapt effectively to the carbon-constrained world we face in the years ahead.

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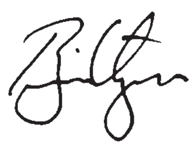

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Introduction

An industry in focus

To support its roadmap work focusing on key technologies for emissions reductions, the International Energy Agency (IEA) also investigated one particular industry: cement. Cement production includes technologies that are both specific to this industry and those that are shared with other industries (e.g., grinding, fuel preparation, combustion, crushing, transport). An industry-specific roadmap provides an effective mechanism to bring together several technology options. It outlines the potential for technological advancement for emissions reductions in one industry, as well as potential cross-industry collaboration.

Cement is the essential "glue" in concrete, a fundamental building material for society's infrastructure around the world. Concrete is second only to water in total volumes consumed annually by society. But producing cement also co-produces CO_2, leading the cement industry to produce approximately 5% of current global man-made CO_2 emissions. With climate change mitigation and adaptation measures increasing, concrete demand is expected to increase even further. In developing countries in particular, cement production is forecast to grow as modernisation and growth continues. 2006 global production was 2.55 billion tonnes (USGS, 2008). A low growth demand scenario has been used for the roadmap with 2050 production at 3.69 billion tonnes. A high growth scenario, with 2050 production at 4.40 billion tonnes, was also modeled, with details in Annex III[1]. It is also clear that product substitution at a sufficient scale for real impact is not an option for at least the coming decade. However, in recent years the cement industry has achieved a partial decoupling of economic growth and absolute CO_2 emissions: global cement production increased by 54% from 2000 to 2006 (USGS 2008), whereas absolute CO_2 emissions increased by an estimated 42% (560 Mt) reaching 1.88 Gt[2] in 2006 (IEA). However, this trend cannot continue indefinitely – wherever the growth of market demand for concrete and cement outpaces the technical potential to reduce CO_2 emissions per tonne of product, absolute CO_2 emissions will continue to increase.

1 Cement demand forecast is a crucial parameter to assess potential emissions reductions. A higher demand will imply either lower absolute reductions achievable over time, faster implementation of carbon capture and storage (CCS), or a combination of both. A range of forecasts are found in different studies undertaken: see Annex III.

2 1.88Gt CO_2 emissions is from direct energy and process emissions only.

WBCSD Cement Sustainability Initiative (CSI)

The members of the CSI – a voluntary business initiative – have been addressing climate change issues for more than a decade. Although there are known negative environmental impacts from cement manufacture, there are also known benefits of using concrete. Concrete can endure for centuries with limited costs for maintenance or repair, and at the end of its life it is recyclable (into aggregates). A well-designed concrete building typically consumes 5-15% less heat than an equivalent building of lightweight construction, and requires less internal heating and cooling services. Over its lifetime, concrete slowly absorbs CO_2 from the air (carbon sequestration). It has a high albedo effect, meaning many solar rays are reflected and less heat is absorbed, resulting in cooler local temperatures and reduced "urban heat island" effects. Cement is also produced and supplied locally. The CSI is currently working to understand the impact of cement's whole life cycle, i.e., as concrete and recycled aggregates, and a potential next step from this roadmap is the development of a technology roadmap considering this.

Drafting this roadmap

The roadmap is based on a model for the cement industry in the context of IEA's BLUE scenarios, which examine the implications of an overall policy objective to halve global energy-related CO_2 emissions in 2050 compared to the 2006 level (BLUE scenario, IEA 2008). According to the Intergovernmental Panel on Climate Change (IPCC), the BLUE scenarios are consistent with a global rise in temperatures of 2-3°C, but only if the reduction in energy-related CO_2 emissions is combined with deep cuts in other greenhouse gas emissions. The roadmap is based on model data from *Energy Technology Transitions for Industry* (IEA, 2009).

Energy Technology Perspectives (ETP) 2008 BLUE Map Scenario

ETP BLUE map scenario describes how the global energy economy may be transformed by 2050 to achieve the global goal of halving annual CO_2 emissions rates. The model is a bottom-up MARKAL model that uses cost optimisation to identify least-cost mixes of energy technologies and fuels to meet energy demand, given constraints such as the availability of natural resources. The ETP model is a global 15-region model that permits the analysis of fuel and technology choices throughout the energy system. The model's detailed representation of technology options includes about 1,000 individual technologies. In addition, the ETP model was supplemented with detailed demand-side models for all major end-uses in the industry, buildings and transport sectors.

The roadmap's technology mitigation options are outlined in a set of 38 technology papers developed by the European Cement Research Academy (ECRA) sponsored by the CSI. The specific reduction potentials contributing to the roadmap have been selected by IEA. The papers outline existing and potential technologies, their estimated costs, implementation timelines and reduction potential. The papers focus on four distinct "reduction levers" available to the cement industry: thermal and electric efficiency, alternative fuel use, clinker substitution, and carbon capture and storage (CCS). Critically, all of these technologies and opportunities need to be applied together if the targets of the BLUE scenarios are to be achieved – no one option alone can yield the necessary emissions reductions.

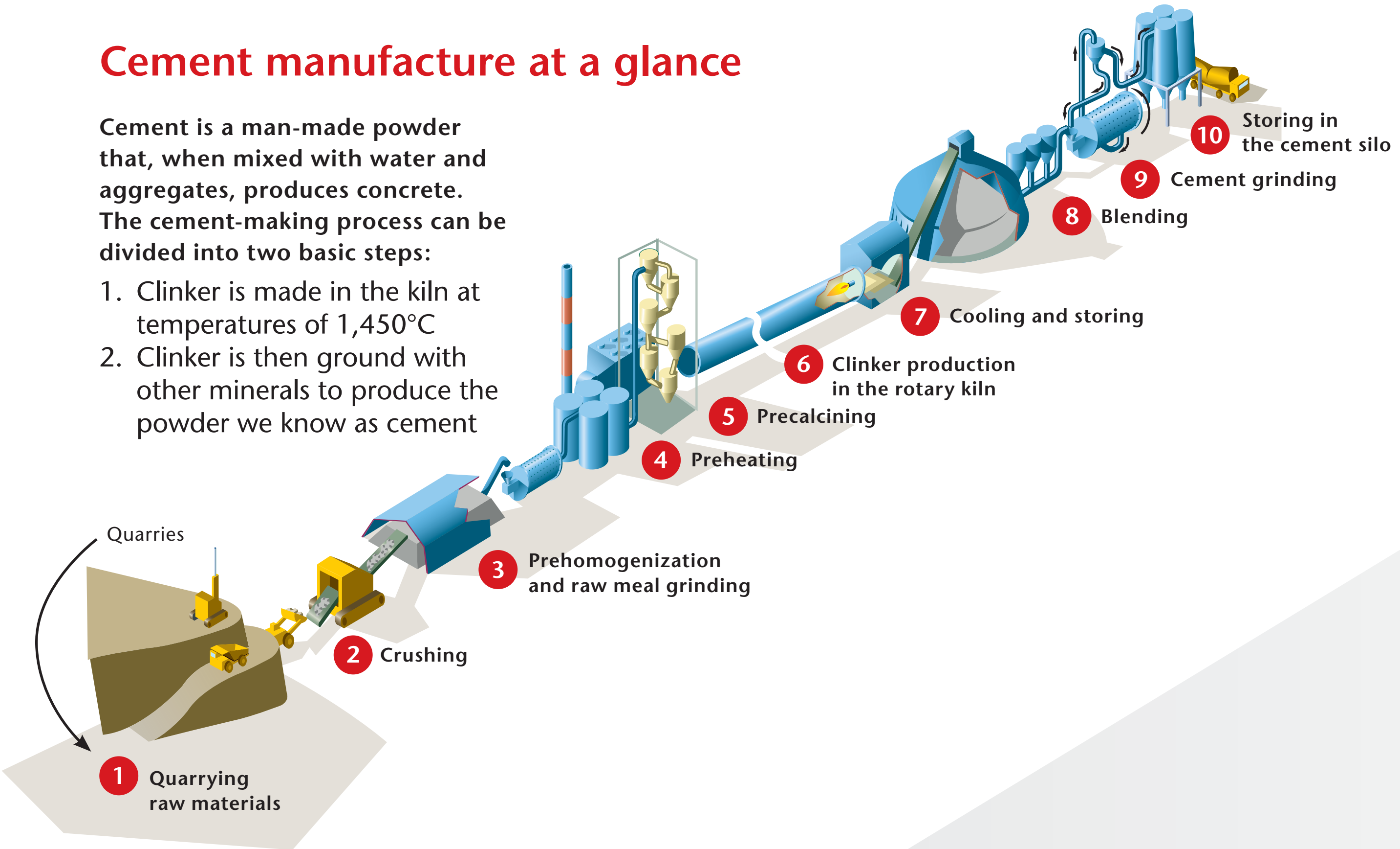
While the papers are based on current knowledge about technology development, they also offer a vision of potential future emissions reductions. The papers do not envisage a major breakthrough technology in cement manufacture, so the importance of CCS is critical if the industry is going to reduce its emissions significantly. But even with CCS development and implementation, the cement industry could not be carbon neutral within its existing technology, financing and innovation framework. No alternative for concrete as a major global construction material currently exists that can be applied at sufficient scale. Other materials can be substitutes in some applications, but not for such broad applications as current concrete use.

The technology papers can be found at www.wbcsdcement.org/technology

Cement manufacture at a glance

Cement is a man-made powder that, when mixed with water and aggregates, produces concrete. The cement-making process can be divided into two basic steps:

1. Clinker is made in the kiln at temperatures of 1,450°C
2. Clinker is then ground with other minerals to produce the powder we know as cement



1. Quarrying raw materials
Naturally occurring calcareous deposits such as limestone, marl or chalk provide calcium carbonate ($CaCO_3$) and are extracted from quarries, often located close to the cement plant. Very small amounts of "corrective" materials such as iron ore, bauxite, shale, clay or sand may be needed to provide extra iron oxide (Fe_2O_3), alumina (Al_2O_3) and silica (SiO_2) to adapt the chemical composition of the raw mix to the process and product requirements.

2. Crushing
The raw material is quarried and transported to the primary/secondary crushers and broken into 10cm large pieces.

3. Prehomogenization and raw meal grinding
Prehomogenization takes place in which different raw materials are mixed to maintain the required chemical composition, and the crushed pieces are then milled together to produce "raw meal". To ensure high cement quality, the chemistry of the raw materials and raw meal is very carefully monitored and controlled.

4. Preheating
A preheater is a series of vertical cyclones through which the raw meal is passed, coming into contact with swirling hot kiln exhaust gases moving in the opposite direction. In these cyclones, thermal energy is recovered from the hot flue gases, and the raw meal is preheated before it enters the kiln, so the necessary chemical reactions occur faster and more efficiently. Depending on the raw material moisture content, a kiln may have up to six stages of cyclones with increasing heat recovery with each extra stage.

5. Precalcining
Calcination is the decomposition of limestone to lime. Part of the reaction takes place in the "precalciner", a combustion chamber at the bottom of the preheater above the kiln, and part in the kiln. Here, the chemical decomposition of limestone typically emits 60-65% of total emissions. Fuel combustion generates the rest, 65% of which occur in the precalciner.

6. Clinker production in the rotary kiln
The precalcined meal then enters the kiln. Fuel is fired directly into the kiln to reach temperatures of up to 1,450°C. As the kiln rotates, about 3-5 times per minute, the material slides and tumbles down through progressively hotter zones towards the flame. The intense heat causes chemical and physical reactions that partially melt the meal into clinker.

7. Cooling and storing
From the kiln, the hot clinker falls onto a grate cooler where it is cooled by incoming combustion air, thereby minimising energy loss from the system. A typical cement plant will have clinker storage between clinker production and grinding. Clinker is commonly traded.

8. Blending
Clinker is mixed with other mineral components. All cement types contain around 4-5% gypsum to control the setting time of the product. If significant amounts of slag, fly ash, limestone or other materials are used to replace clinker, the product is called "blended cement".

9. Cement grinding
The cooled clinker and gypsum mixture is ground into a grey powder, Ordinary Portland Cement (OPC), or ground with other mineral components to make blended cement. Traditionally, ball mills have been used for grinding, although more efficient technologies - roller presses and vertical mills - are used in many modern plants today.

10. Storing in the cement silo
The final product is homogenised and stored in cement silos and dispatched from there to either a packing station (for bagged cement) or to a silo truck.

Note: There are older, much less efficient technologies, for example the wet kiln into which the raw material is fed as slurry and not as a powder (dry kiln).

Carbon emissions reduction levers

Several different studies (IEA (2008, 2009), CSI (2009), ECRA (2009), CCAP (2008), McKinsey (2008)) have focused on potential cement industry emissions reductions. Using different scenarios, baseline emissions and future demand forecasts, they nevertheless reach broadly similar conclusions, and highlight the impacts of the four levers for carbon emissions reductions:

1. Thermal and electric efficiency – deployment of existing state of the art technologies in new cement plants, and retrofit of energy efficiency equipment where economically viable.
2. Alternative fuels – use of less carbon-intensive fossil fuels and more alternative (fossil) fuels and biomass fuels in the cement production process. Alternative fuels include wastes that may otherwise be burnt in incinerators, landfilled or improperly destroyed.
3. Clinker substitution – substituting carbon-intensive clinker, an intermediate in cement manufacture, with other, lower carbon, materials with cementitious properties.
4. Carbon capture and storage (CCS) – capturing CO_2 before it is released into the atmosphere and storing it securely so it is not released in the future.

It is often the case that each individual lever has an influence on the potential of another lever to reduce emissions. For example the use of alternative fuels will generally increase specific heat consumption (e.g., because of higher moisture levels). Therefore simply adding up the reduction potentials of each technology in order to calculate total potentials is not feasible. Emissions reduction potential is based on net emissions.

Potential low-carbon cements

A number of low-carbon or carbon-negative cements are currently being developed by start-up companies expecting to build pilot plants in 2010/11. The mechanical properties of these cements appear to be similar to those of Portland cement. However, these new processes are still at the development stage. They are currently neither proven to be economically viable nor tested at scale for their long-term suitability. Nor have their products been accepted in the construction industry where strong material and building standards exist. As and when the first production plants come on stream, initial applications are likely to be limited and apply to niche markets, pending widespread availability and customer acceptance.

It is therefore not known whether they can have an impact on the future cement industry. As a result they have not been included in the roadmap analysis. In the long term they may offer opportunities to reduce the CO_2 intensity of cement production, and their progress should be followed carefully and potentially supported by governments and industry.

- **Novacem** is based on magnesium silicates (MgO) rather than limestone (calcium carbonate) as is used in Ordinary Portland Cement. Global reserves of magnesium silicates are estimated to be large, but these are not uniformly distributed and processing would be required before use. The company's technology converts magnesium silicates into magnesium oxide using a low-carbon, low temperature process, and then adds mineral additives that accelerate strength development and CO_2 absorption. This offers the prospect of carbon-negative cement.
- **Calera** is a mixture of calcium and magnesium carbonates, and calcium and magnesium hydroxides. Its production process involves bringing sea-water, brackish water or brine into contact with the waste heat in power station flue gas, where CO_2 is absorbed, precipitating the carbonate minerals.
- **Calix's** cement is produced in a reactor by rapid calcination of dolomitic rock in superheated steam. The CO_2 emissions can be captured using a separate CO_2 scrubbing system.
- **Geopolymer cement** utilises waste materials from the power industry (fly ash, bottom ash), the steel industry (slag), and from concrete waste, to make alkali-activated cements. The performance of such a system is dependent on the chemical composition of the source materials, the concentration of sodium hydroxide (NaOH) and potassium hydroxide (KOH) chemical activators, and the concentration of soluble silicates. Geopolymer cements have been commercialised in small-scale facilities, but have not yet been used in large-scale applications where strength is critical. This process was developed in the 1950s.

Technology

Thermal and electric efficiency

When building new cement plants, manufacturers install the most recently developed technologies, which are also typically the most energy efficient. Therefore new kilns are comparatively very energy efficient. More efficient technologies generally provide a cost advantage to the producer through lower energy costs, so efficiency does increase gradually over time with the addition of new plants and upgrading of old plants.

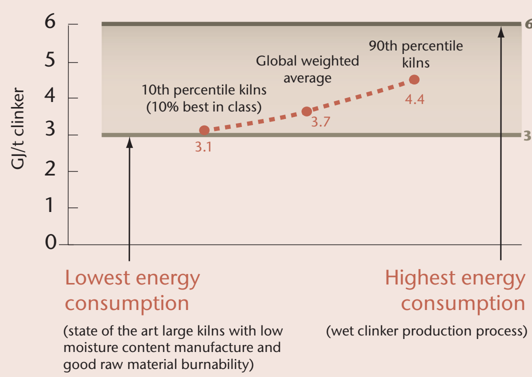
There is a very wide range of technologies available, and savings on a per unit basis range from 0.2-3.5 GJ/tonne clinker. The industry is phasing out inefficient long dry kilns and the wet production process. Market and economic forces generally trigger the closure of inefficient facilities as more advanced technologies are commissioned.

The thermal efficiency of an installation is largely defined by its original engineering design. However, after installation, the efficiency at which the machinery is operated and maintained is key to ensuring that maximum potential operational efficiencies are achieved. This operational efficiency varies by technology, and is hard to measure, but is an important aspect of energy and emissions management. Current state of the art is the dry manufacturing process with preheater and precalciner technology. Based on the CSI's "Getting the Numbers Right" (GNR) data, the weighted average of the specific thermal energy consumption for this kiln type in 1990 was 3,605 MJ/t clinker, and in 2006 was 3,382 MJ/t clinker; this indicates a reduction of around 220 MJ/t clinker (6%) over 16 years.

Efficiency is a function of initial and subsequent cement plant investments, which are often dictated by local energy prices. For example, companies operating in India invest strongly in electrical efficiency as well as thermal efficiency measures because of high energy prices and inadequate availability of coal (the main fuel in India), and hence partial dependency on more expensive imported coal. As electricity supply is unreliable in many areas of the country, cement producers install their own captive power plants with high efficiency boilers and, more recently, waste heat recovery installations.

Of the four emissions reductions levers, only energy efficiency is managed by the industry itself – the others are influenced to a large extent by policy and legal frameworks.

Range of thermal efficiency (clinker)



Source: Getting the Numbers Right data 2006, WBCSD

Electric efficiency (cement)

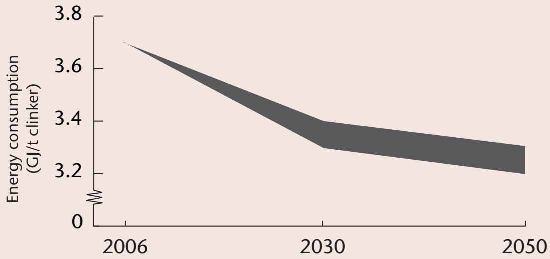
Electric energy consumption for cement manufacture	kWh/t cement
10th percentile mills	89
Global weighted average	111
90th percentile mills	130

Note: Figures are for blended and Portland cement
Source: Getting the Numbers Right data 2006, WBCSD

Projected thermal energy consumption for a cement plant using state of the art technology kiln

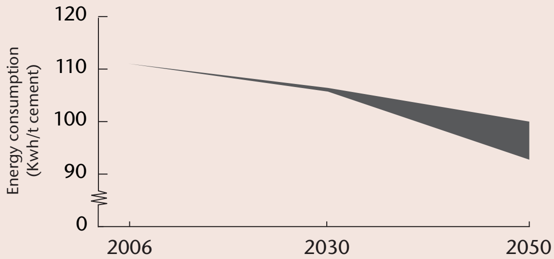
Thermal efficiency

Thermal energy consumption for clinker manufacture in different years:



Electric efficiency (approximately 10% of energy consumed)

Electric energy consumption for cement manufacture in different years (without CCS):



Source: ECRA Technology Papers (2009)

Note: Both graphs show estimated averages

Note: The IEA forecast includes global decarbonisation of electricity by 2050. This forecast is used only in the mitigation case and not in the baseline, therefore CO_2 emissions and CCS volumes in the mitigation case are not affected by electric efficiency.

Limits to implementation

Theoretical minimum primary energy consumption (heat) for the chemical and mineralogical reactions is approximately 1.6-1.85 GJ/t (Locher, 2006). However, there are technical reasons why this will not be reached, for example unavoidable conductive heat loss through kiln/calciner surfaces.

However, for reduction of the specific power consumption (electricity), other barriers are also preventing the industry from reaching this minimum, for example:

- A significant decrease in specific power consumption will only be achieved through major retrofits. These have **high investment costs** and so retrofits are currently limited.
- **Strengthened environmental requirements** can increase power consumption (e.g., dust emissions limits require more power for dust separation regardless of the technology applied).
- The **demand for high cement performance**, which requires very fine grinding and uses significantly more power than low-performing cement.
- It is generally accepted that **CCS** is key to reducing CO_2 emissions, but has been estimated to increase power consumption by 50-120% at plant level (power for air separation, stripping, purification, CO_2 compression, etc.).
- **Other reduction levers** can be negatively correlated with energy efficiency, for example clinker substitutes such as slag and fly ash reduce CO_2 emissions in the clinker production process but generally require more energy for grinding cement finely.

R&D needs and goals

The fluidised bed is a promising technology to improve thermal efficiency and is widely used in some other industries. It has yet to prove its suitability at scale in the cement industry. Other breakthrough technologies that could lead to a significantly higher thermal or electric efficiency are not envisaged. Therefore it is vital to ensure that new plants are fitted with the most efficient technologies, and are then operated and maintained well.

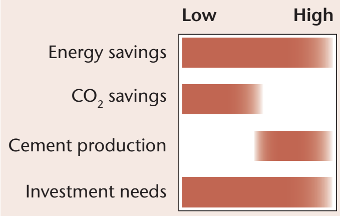
New grinding equipment and additives are also being investigated to reduce the specific electricity consumption of grinding mills. This existing technology needs ongoing R&D to ensure maximum progress is reached. It must be noted that the efficiency-related emissions reductions in the BLUE scenario are an effect of the replacement of old kilns with newer, more efficient kilns, not a technology development as such.

Partner roles

item/partner	industry	industry suppliers	governments	universities	research institutes
best practice	x	x			
technology research	x $	x $	$	x	x
technology diffusion	x $	x	$		
institutional structure	x	x	x	x	x
performance data	x				

x = leadership role and direct involvement required
$ = funding source

Potential impacts



Note: The table on partner roles above shows the different roles stakeholders must take to enable development and implementation of thermal and electric efficiency technologies, and the funding sources for those developments. A similar table is shown for each carbon emissions reduction lever in this roadmap.

Note: The chart on potential impacts above shows the potential impacts of increased energy efficiency in cement manufacture, on each of the different issues detailed on the left-hand side. Where the range of potential impacts could be large, low to high is coloured, and where there is more clarity on the potential impact, only the relevant scale of impact is coloured. A similar chart is shown for each carbon emissions reduction lever in this roadmap, each related to that lever specifically.

Technology

Alternative fuel use

Alternative fuel use entails replacing conventional fuels (mainly coal and/or petcoke), which heat the cement kiln, with alternative fossil fuels (including natural gas) and biomass fuels. The mixed fuel can be 20-25% less carbon intensive than coal (IEA emission factors used in the roadmap are in Annex I[3]). Cement kilns are particularly well-suited for such fuels for two reasons: the energy component of alternative fuels is used as a substitute for fossil fuels; and the inorganic components e.g., ashes, are integrated into the clinker product. These can be effective substitutes with lower CO_2 emissions than traditional solid fuels.

Life cycle analysis shows that: a) if these materials would otherwise be considered as waste and incinerated, additional fossil fuels would be needed in the incineration process, themselves emitting CO_2, and b) using alternative fuels prevents unnecessary land-filling of wastes.

3 IEA model assumes 40% biomass in alternative fuels, a high figure compared with the current situation

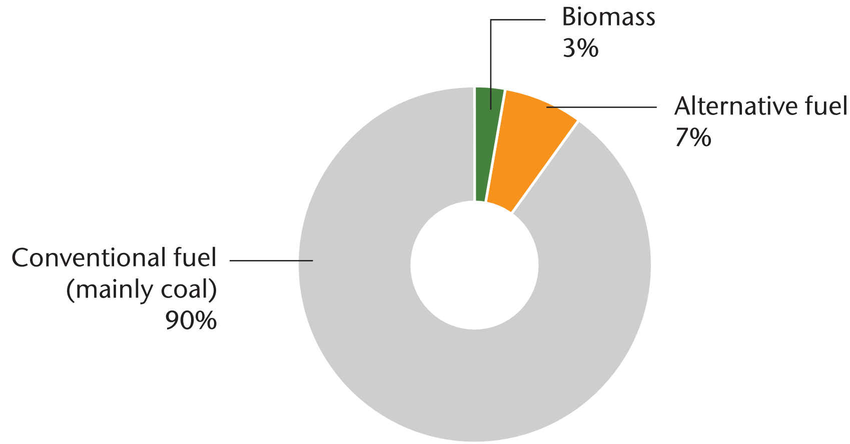
Typical alternative fuels used by the cement industry

- Pre-treated industrial and municipal solid wastes (domestic waste)
- Discarded tyres
- Waste oil and solvents
- Plastics, textiles and paper residues
- Biomass
  - > Animal meal
  - > Logs, wood chips and residues
  - > Recycled wood and paper
  - > Agricultural residues like rice husk, sawdust
  - > Sewage sludge
  - > Biomass crops

Alternative fuel in focus: discarded tyres
An estimated one billion tyres reach the end of their useful lives every year globally. Cement kilns are able to use either whole or shredded tyres as tyre-derived fuel, which is the biggest use for discarded tyres in Japan and the USA. Tyres have higher energy content than coal and, when burned in a controlled environment, emissions are no greater than those of other fuels. In some cases, using tyre-derived fuel instead of virgin fossil fuels reduces nitrogen dioxide, sulphur dioxide and carbon dioxide emissions. Heavy metal residues are captured and locked into the clinker.

GNR participants’ alternative fuel use (2006)

Percentage of total fuel consumption per fuel source



Source: Getting the Numbers Right data 2006, WBCSD

Technically, much higher substitution rates are possible. In some European countries, the average substitution rate is over 50% for the cement industry and up to 98% as yearly average for single cement plants. As fuel-related CO_2 emissions are about 40% of total emissions from cement manufacture, the CO_2 reduction potential from alternative fuel use can be significant.

Due to a high carbon price and the various fuel prices assumed in the model calculations by 2050, it becomes economically attractive to switch kiln fuel from coal and petcoke to natural gas. As natural gas has a significantly lower carbon content, the effect of this change on emissions reductions is more significant than the effect of increased alternative fuel use, of energy efficiency or of clinker substitution. In this roadmap, this "fuel-switching" is included within the category of "alternative fuel use", as both relate to the same fundamental lever, the average carbon intensity of the fuel mix.

Limits to implementation

Although, technically, cement kilns could use up to 100% of alternative fuels, there are some **practical limitations**. The physical and chemical properties of most alternative fuels differ significantly from those of conventional fuels. While some (such as meat-and-bone meal) can be easily used by the cement industry, many others can cause technical challenges. These are related to, for example, low calorific value, high moisture content, or high concentration of chlorine or other trace substances. For example, volatile metals (e.g., mercury, cadmium, thallium) must be managed carefully, and proper removal of cement kiln dust from the system is necessary. This means **pre-treatment** is often needed to ensure a more uniform composition and optimum combustion.

However, the achievement of higher substitution rates has stronger political and legal barriers than technical ones:

- **Waste management legislation** significantly impacts availability: higher fuel substitution only takes place if local or regional waste legislation restricts land-filling or dedicated incineration, and allows controlled waste collection and treatment of alternative fuels.
- **Local waste collection networks** must be adequate.
- **Alternative fuel costs** are likely to increase with high CO_2 costs. It may then become increasingly difficult for the cement industry to source significant quantities of biomass at acceptable prices. This roadmap assumes it will be economically viable for the cement industry to use alternative fuels until 2030, when prices will reach about 30% of conventional fuel costs, increasing to 70% by 2050.
- The **level of social acceptance** of co-processing waste fuels in cement plants can strongly affect local uptake. People are often concerned about harmful emissions from co-processing, even though emissions levels from well-managed cement plants are the same with or without alternative fuel use.

In addition, alternative fuel use has the potential to increase thermal energy consumption, for example when pre-treatment is required as outlined above.

R&D needs and goals

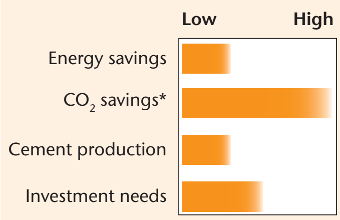
Suitable materials that could be used as alternative fuels must be identified and classified. R&D of the processing and use of such fuels need to be shared, to enable widespread expertise in using high and stable volumes of alternative fuels.

Partner roles

item/partner	industry	industry suppliers	governments (including local municipalities)	universities	research institutes
best practice	x	x			
technology research	x $	x $	$	x	x
technology diffusion	x $	x $	$		
institutional structure	x	x	x	x	x
performance data	x				

x = leadership role and direct involvement required
$ = funding source

Potential impacts

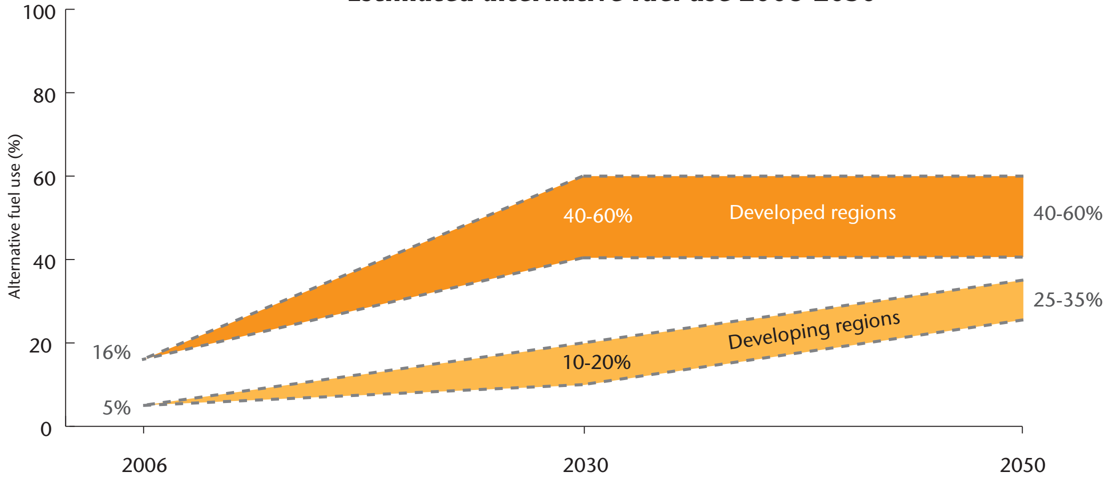


* Range given depends on the definition of alternative fuel used

Regional perspective

The use of waste as an alternative energy source varies widely across regions and countries, and is mainly influenced by the types of local industry, the level of development of waste legislation, regulatory frameworks and enforcement, waste collection infrastructure and local environmental awareness.

Estimated alternative fuel use 2006-2050



Source: ECRA Technology Papers (2009), Getting the Numbers Right data 2006 (WBCSD), IEA (2009)
Note: the maximum levels in each region depend on competition from other industries for alternative fuels

Further geographical analysis of GNR data shows that alternative fuels contribute 20% of energy needed in European cement plants (15% fossil and 5% biomass). North America and Japan-Australia-New Zealand source 11% from waste, essentially alternative fossil fuel. Latin America sources 10% alternative energy (6% fossil, 4% biomass). Asia has begun such sourcing and reached a 4% substitution rate in 2006 (2% fossil, 2% biomass). In Africa, the Middle East and the Commonwealth of Independent States (CIS), alternative energy sourcing is insignificant.

Even within developed regions, large differences in alternative fuel use occur, for example 98% in the Netherlands but nearer 0% in Spain. This means the averages used in the graph above does not show the very broad range possible. Individual country cases should be considered in more detail. A key barrier to higher alternative fuel use is often fuel availability. In Maastricht in the Netherlands, alternative fuel use in 2008 was 98%, which dropped to 89% in 2009 due to limited availability. In Japan, the estimated maximum alternative fuel use in 2030 is 20% including biomass, due to limited availability. In other areas, scarcity of land for waste disposal is an important primary driver of the level of local environmental awareness or waste legislation.

The CSI member companies, following IPCC 1996 guidelines for national greenhouse gas inventories, consider that biomass fuels are climate-neutral when sustainably harvested (because emissions can be compensated by biomass re-growth in the short term). The cement industry reports gross emissions as the total direct CO_2 emissions from a cement plant or company in a given period. Gross emissions include CO_2 from alternative fossil fuels, but exclude CO_2 from biomass fuels.

Using alternative fuels in the cement industry typically results in greenhouse gas emissions reductions at landfills (e.g., methane) and incineration plants where these materials might otherwise be disposed. These indirect emissions reductions can be lower, equal or higher than the direct CO_2 emissions from alternative fuel combustion at the cement plant, depending on the type of waste and the alternative disposal path no longer used. This results in overall reductions in CO_2 emitted. In conjunction with projected increases in the costs of biomass, and decreases in availability, the combination of direct emissions impacts, indirect emissions reductions and resource efficiency makes alternative fuel substitution for conventional fossil fuels an effective way to reduce global greenhouse gas emissions. For these reasons the cement industry also reports the net emissions in which the emissions from alternative fossil fuels are deducted from the gross emissions.

If all alternative fuels (including alternative fossil fuels) are treated as carbon neutral, the calculated emissions reductions in 2050 rise from 18% to approximately 24% for the cement industry.

Technology

Clinker substitution

Clinker is the main component in most types of cement. When ground and mixed with 4-5% gypsum, it reacts with water and hardens. Other mineral components also have these hydraulic properties when ground and mixed with clinker and gypsum, notably ground blast furnace slag (a by-product from the iron or steel industry), fly ash (a residue from coal-fired power stations) and natural volcanic materials. These can be used to partially substitute clinker in cement, therefore reducing the volumes of clinker used, and also the process-, fuel- and power-related CO_2 emissions associated with clinker production.

The clinker content in cement (the "clinker to cement ratio") can vary widely, although the extremes are only used for special applications. Ordinary Portland Cement can contain up to 95% clinker (the balance being gypsum). Based on 2006 GNR data, the global average clinker ratio was 78%, equivalent to more than 500 million tonnes of clinker-substituting materials used for 2,400 million tonnes of cement produced. But there are very wide regional differences (centre spread)[4].

4 Different national industry structures exist, for example in most European countries clinker substitutes are added to the clinker at the plant, which drives the clinker to cement ratio down, whereas in the US and Canada, clinker substitutes are typically added at the concrete level (i.e. in the ready-mix plant).

Clinker substitute	Source	Positive characteristics	Limiting characteristics	Estimated annual production level	Availability
Ground blast furnace slag	Iron or steel production	Higher long term strength and improved chemical resistance	Lower early strength and higher electric power demand for grinding	200 million tonnes (2006)	Future iron and steel production volumes are very difficult to predict
Fly ash	Flue gases from coal-fired furnaces	Lower water demand, improved workability, higher long term strength, better durability (depending on application)	Lower early strength, availability may be reduced by change in fuel sources by the power sector	500 million tonnes (2006)	Future number and capacity of coal-fired power plants is very difficult to predict
Natural pozzolanas (e.g., volcanic ash), rice husk ash, silica fume	Volcanoes, some sedimentary rocks, other industries	Contributes to strength-development, can demonstrate better workability, higher long term strength and improved chemical resistance	Most natural pozzolanas lead to reduced early strength, cement properties may vary significantly	300 million tonnes available (2003) but only 50% used	Availability depends on local situation – many regions do not provide use of pozzolana for cement
Artificial pozzolanas (e.g., calcined clay)	Specific manufacture	Similar to natural pozzolanas	Calcination requires extra thermal energy and so reduces positive CO_2 abatement effect	Unknown	Very limited availability due to economic constraints
Limestone	Quarries	Improved workability	Maintaining strength may require additional power for grinding clinker	Unknown	Readily available

Source: ECRA Technology Papers (2009)

Limits to implementation

From a technical point of view, low clinker to cement ratios are possible for certain concrete products, but five non-technical factors can create barriers:

- **Regional availability** of clinker-substituting materials
- Increasing **prices** of substitution materials
- **Properties** of substitution materials and **intended application** of the cement
- **National standards** for Ordinary Portland Cement and composite cements
- **Common practice and acceptance** of the composite cements by construction contractors and customers

There is uncertainty around future availability of clinker substitutes, which may be impacted greatly by environmental policy and regulation. For example, with any future decarbonisation of the power sector, the availability of fly ash could be constrained, or when DeNOx techniques[5] are applied in coal-fired power stations to reduce NOx emissions, resulting fly ash may be unusable as a clinker substitute due to excessive NH_3 (ammonia) concentrations.

R&D needs and goals

Documented assessment of substitution material properties is needed, to understand and communicate which substitutes are best for which intended applications. For example, cement standards allow up to 95% blast furnace slag in some cement. However, this has low early-stage strength. These cements are only suitable for very special applications, and their use depends on their availability. It would be valuable to develop and cross-reference roadmaps for different industries which are linked to the cement industry by the production of clinker substitutes. This will enable forecasting of the effects of mitigation technologies in one industry impacting mitigation potential in other industries.

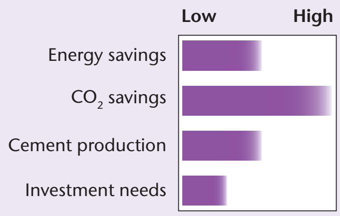
5 Process to remove nitrogen oxides (NOx) from gases

Partner roles

item/partner	industry	industry suppliers	governments (in this case including national laboratories)	universities	research institutes	standardi-sation bodies
best practice	x	x	x	x	x	x
technology research	x $	x	$	x	x	x
technology diffusion	x $	x	$		x	x
institutional structure	x	x	x	x	x	x
performance data	x		x			x

x = leadership role and direct involvement required
$ = funding source

Potential impacts



Technology

Carbon capture and storage

(Note: this roadmap is limited to capture technologies. The IEA roadmap on CCS contains more detail on the full CCS chain including transport and storage: www.iea.org/Papers/2009/CCS_Roadmap.pdf)

Carbon Capture and Storage (CCS) is a new technology, not yet proven at the industrial scale in cement production, but potentially promising. CO_2 is captured as it is emitted, compressed to a liquid, then transported in pipelines to be permanently stored deep underground. In the cement industry, CO_2 is emitted from fuel combustion and from limestone calcination in the kiln. These two CO_2 sources may require industry-specific capture techniques that are low-cost and efficient, and literature studies show that some capture technologies seem more appropriate for cement kilns than others.

See *CO_2 Capture and Storage – A Key Carbon Abatement Option* (IEA, 2008) for more information on CCS technologies. The cement industry is already active in R&D for CO_2 capture. It is important to keep in mind that capture technologies only have value when the full chain of CCS is available, including transport infrastructure, access to suitable storage sites, and a legal framework for CO_2 transport and storage, monitoring and verification, and licensing procedures.

Up to now, pre-combustion technologies have never been used in a cement plant. Firstly, CO_2 emissions originating from the calcination of limestone, the source of the majority of emissions in cement production, would remain unabated even if pre-combustion technologies were used. In addition, pure hydrogen has explosive properties and the clinker-burning process would need significant modifications. Therefore, the focus of this roadmap is on CO_2 capture technologies appropriate for cement production:

1. Post-combustion technologies are end-of-pipe mechanisms that would not require fundamental changes in the clinker-burning process, and so could be available for new kilns and in particular for retrofits:

- Chemical absorption is most promising and high CO_2 capture rates have been achieved in other industries, using amines, potassium and other chemical solutions.
- Membrane technologies may also be used at cement kilns in the long term, if suitable materials and cleaning techniques are developed.
- Carbonate looping, an adsorption process in which calcium oxide is put into contact with the combustion gas containing carbon dioxide to produce calcium carbonate, is a technology currently being assessed by the cement industry as a potential retrofit option for existing kilns, and in the development of new oxy-firing kilns. In addition, synergies with power plants can be generated (power plants' deactivated absorbents could be re-used as a secondary raw material in cement kilns).
- Technologies for other post-combustion measures (e.g., physical absorption or mineral adsorption) are currently much less developed.

2. Oxyfuel technology, using oxygen instead of air in cement kilns, would result in a comparatively pure CO_2 stream. Extensive research is still required to understand all potential impacts on the clinker-burning process. Oxyfuel technology is now being demonstrated at small-scale power plants, so results obtained may be helpful to future cement kilns.

From a technical point of view, carbon capture technologies in the cement industry are not likely to be commercially available before 2020. Before then, early research and pilot tests are needed to gain practical experiences with these new developing technologies. Some have started, for example research by ECRA and pilots in California and the UK. Between 2015 and 2020, large-scale demonstration projects will be initiated (especially on post-combustion technologies), but total CO_2 reductions will still be low. A rough estimation, based on 10-20 large kiln projects globally (average 6,000 tonnes per day) and a reduction efficiency of 80%, would lead to an overall CO_2 emission reduction of maximum 20-35 Mt per year. After 2020, CCS could become commercially implemented if the political framework is supportive and social acceptance is achieved.

Due to higher specific costs, it is expected that kilns with a capacity of less than 4,000-5,000 tonnes per day will not be equipped with CCS technology, and that retrofits will not be common. As CCS requires CO_2 transport infrastructure and access to storage sites, cement kilns in industrialised regions could be connected more easily to grids, compared to plants in non-industrialised areas. For oxyfuel technology, commercial availability could be achieved in 2025.

Cost estimations for post-combustion carbon capture using chemical absorption technologies for a 2 Mt per annum clinker plant

	New installation / retrofit	
	Investment (Mio€)	Operational (€/t clinker)
2015	Not available	Not available
2030	100-300	10-50
2050	80-250	10-40

Source: ECRA Technology Papers(2009)
Note: the costs provided are estimations based on ECRA calculations (2009). Investment costs have been indicated as additional to the cement plant investment cost, and do not include transport or storage.

Limits to implementation

Besides technical aspects, the **economic framework** will be decisive for future applications of CCS in the cement industry. Although it is expected that the cost of CCS will decrease in the future according to technical and scientific progress, current estimated costs for CO_2 capture are high. They range from EUR20 to over EUR75 per tonne of CO_2 captured (EUR20/t CO_2 is likely to be achievable only under very favourable circumstances and is not representative of the average cost of mass deployment of CCS).

CCS could be applied in the cement industry only if the **political framework** effectively limits the risk of carbon leakage (relocation of cement production into countries or regions with fewer constraints). Public awareness of CCS is currently low, and the public has not yet formed a firm opinion of CCS and its role in mitigating climate change (IRGC, 2008). Public support is critical and should be developed in a variety of ways:

- **Political support** for government incentives, funding for research, long term liability and the use of CCS as a component of a comprehensive climate change strategy.
- **Property owners' cooperation** to obtain necessary permits and approvals for CO_2 transportation and storage sites.
- **Local residents' informed approval** of proposed CCS projects in their communities.
- Expanded efforts by government and industry to **educate and inform the public and key stakeholders** about CCS.

R&D needs and goals

CCS measures for the cement industry are being discussed, but to date only a few feasibility studies have been carried out and no results from pilot or industrial-scale trials at cement kilns are available. Oxyfuel technology in particular needs further extensive development to bring CCS technologies to scale in the industry.

Transportation is the crucial link between CO_2 emission sources and storage sites, and insufficient attention has been paid to technology and infrastructure needs. Pipeline transportation presents different regulatory, access and development challenges in different regions, and the magnitude, complexity and geographic spread for integrated CCS transport pipelines requires a clear focus on this.

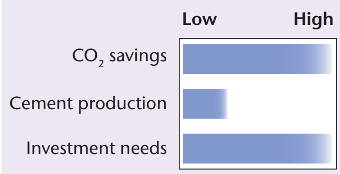
As storage site availability on a global level is only beginning to be understood, a detailed estimation of potential CCS implementation is not yet possible. There is a need for additional funding for advanced storage site characterisation if CCS is to be successful at a commercial scale for all industries. Cement kilns are usually located near large limestone quarries, which may or may not be near suitable CO_2 storage sites. It is also likely that CCS clusters will be influenced by proximity to much larger CO_2 sources such as major coal-fired power plants. CO_2 storage prospectivity studies must expand and cover developing countries, where an estimated 80% of all new cement capacity to 2050 will be located. Much work is also needed by governments to develop common, harmonised approaches for safe site selection, operation, maintenance, monitoring and verification of CO_2 retention and closure. The cement industry must continue to examine growing interest among bilateral and multilateral donors to support CCS technology transfer and capacity-building.

Partner roles

item/partner	industry	industry suppliers	governments	univer-sities	research institutes	other industries involved in ccs transport and storage
best practice	x		x $ (transport)		x	
technology research	x $	x $	$	x	x	x
technology diffusion	x $	x $	$	x	x	x
institutional structure	x	x	x	x	x $	x
performance data	x	x	x	x	x	

x = leadership role and direct involvement required
$ = funding source

Potential impacts



This roadmap outlines necessary technology implementation to achieve emissions reductions levels of 18% for the cement industry. The following, challenging, figures show how this would be reached through CCS technology implementation. Assuming a cement kiln lifetime of 30-50 years, 20-33% of existing kilns will be replaced by new ones before 2020. Assuming that 50% of future new capacity is large kilns (2Mt per annum), and assuming a CCS implementation rate of 100% for new large kilns, approximately 40-45% of the global capacity could be equipped with CCS between 2030 and 2050. 10% of those kilns are retrofits (ECRA, 2009). This potential replacement schedule can only give an idea of the potential orders of magnitude for replacement in the cement industry, and assumes that transport and storage issues have been solved.

CCS implementation will most likely take place in regions where large new capacities are needed or where large kilns are in operation and could be retrofitted, and where access to suitable storage sites is provided. However, due to cement plant infrastructure's long lifetime, most plants built in the next decade are likely to still be operating in 40-50 years. Curbing emissions by 2050 will require new greenfield and brownfield investments for CO_2 capture-ready plants[6]. These decisions have clear short term economic and political implications that must be carefully evaluated by all stakeholders.

6 A "capture ready" cement plant is one which can include CO_2 capture when the necessary economic and regulatory drivers are in place. Cement plants can be made "capture ready" through a design study on capture retrofit, including sufficient space and access for capture equipment and identifying routes to CO_2 storage.

What policy support is needed?

Any successful implementation of the cement roadmap will only be possible if the policy framework is supportive of the necessary technology development and dissemination. By addressing policy needs, this roadmap aims to propose tangible policy recommendations for governments around the world. Nationally appropriate policies should then be developed to reinforce these recommendations.

1. **Promote the adoption of best available efficiency technologies for new and retrofit kilns**
2. **Encourage and facilitate increased alternative fuel use**
3. **Encourage and facilitate increased clinker substitution**
4. **Facilitate the development of carbon capture and storage (CCS)**
5. **Ensure predictable, objective and stable CO_2 constraints and energy frameworks on an international level**
6. **Enhance Research and Development (R&D) capabilities, skills, expertise and innovation**
7. **Encourage international collaboration and public-private partnerships on technology implementation**

1. Promote the adoption of best available efficiency technologies for new and retrofit kilns

The cement industry has significantly reduced its energy intensity with the development of dry process kilns with preheaters and precalciners. Although a wide range of energy efficient technologies are available, high investment costs and long infrastructure lifetime are often a key barrier to implementation. Further improvements in energy efficiency are possible in many regions, and realizing this potential should be an immediate focus. Implementation is possible through well-known, project support policy instruments even when investment is not economically justified. Joint Implementation projects, such as CRH's renewal of a cement plant in Ukraine with modern, energy efficient technology are good examples of focused policy leading investments in energy efficient technology.

This roadmap recommends:

- Eliminating energy price subsidies that can act as a barrier to implementation of more energy efficient technologies.
- Phasing-out inefficient long-dry kilns and wet production processes in both developed and developing countries.
- Strengthening international cooperation to gather reliable, industry-level energy and emissions data; supporting effective policy development; tracking performance, and identifying regional and national performance gaps and best practice benchmarks, for example through the CSI "Getting the Numbers Right" (GNR) database.
- Developing and implementing international standards for energy efficiency and CO_2 emissions in the cement industry.
- Sharing best practice policies for the promotion of energy efficiency and CO_2 emissions reductions in the cement industry, for example the Asia Pacific Partnership's Centre of Excellence in Beijing focusing on technology diffusion and capacity-building.

2. Encourage and facilitate increased alternative fuel use

Alternative fuel use can prevent fossil fuels being unnecessarily burnt or potential fuel sources being sent to landfill. There is good industry understanding of the process and potential increased implementation; however, appropriate legislative and regulatory frameworks are necessary for further emissions reductions. These must strengthen environmental authorities' capacities for monitoring and enforcement, as well as increase transparency and build community trust. Estimates propose that average global substitution rates could be 30% in 2030, and 35% in 2050, compared to today (however, within that average, the range of alternative fuel use by individual countries could be large).

Current barriers to wider alternative fuel use are variations in availability of alternative fuels and biomass, varying legislative support and enforcement related to co-processing, land-filling and incineration, and poor public understanding and acceptance. Good examples of overcoming such barriers do exist, for example the European Waste Incineration Directive (2006/7), which takes a step-by-step approach to permitting alternative fuel use, and the "*Guidelines for the Selection and Use of Fuels and Raw Materials in the Cement Manufacturing Process*" (CSI, October 2005), categorizing potential alternative fuels.

This roadmap recommends:

- Policy-makers facilitating stakeholder and public understanding of the role of alternative fuel use in emissions reduction. For example in the Norwegian National Waste Policy, cement kilns are the preferred method for hazardous waste management.
- Reviewing and potentially updating regional, national and local level legislation, to ensure the use of alternative fuels and biomass is incentivized by policy, not limited.
- Governments introducing the concept of industrial ecology and promoting the concept of a recycling-based society, for example the National Industrial Symbiosis Programme (NSIP) (UK). Legal and regulatory frameworks must support the development of, for example, industrial parks like Kalundborg (Denmark), or the US BPS | By-Product Synergy regional processes (e.g., Chicago Waste to Profit Network (W2P), Partnership for Industrial Ecology in Central Ohio (PIECO)).
- Ensuring operators follow common sets of guidelines on alternative fuel use to guarantee adequate processes, for example induction and retraining, documenting and monitoring, for employees and contractors.
- Ensuring training of authorities and an adequate technical background of civil servants responsible for permits, control and supervision.
- Government-industry discussions to investigate the concept of mining landfill sites to generate alternative fuels and raw materials (eg because of space needed for urban expansion).

3. Encourage and facilitate increased clinker substitution

Current factors preventing the full potential of clinker substitution from being reached include existing cement standards and building codes; poor understanding of the process by the public and customers; regional and local availability of substitute materials, and new legislation at international and national levels that do not reflect availability. Several local level blended cements have been produced according to new building standard specifications, for example in Europe. They possess somewhat different chemical, physical and mechanical properties from those of conventional Ordinary Portland Cement and their use in concrete must follow specific parameters to ensure adequate structural safety. However, progress in broadening their use has been made. For example the share of production of non-CEM I cements in the EU, as a percentage of all EU cement production, has risen by 13.1% to 72.5% between 1994 and 2004 (CEMBUREAU, 2007)[7].

This roadmap recommends:

- Independent Environmental Impact Studies (EIS) on the use of key substitution materials by the cement and other industries to show where to achieve the highest potential emissions reductions.
- Developing new, or revising existing, cement standards and codes in some countries to allow more widespread use of blended cement, for example, basing standards on performance rather than composition, and ensuring they are accepted by local authorities.
- R&D into processing techniques for potential clinker substitutes that cannot currently be used due to quality constraints.
- Promoting international training events with national standardisation bodies and accreditation institutes to exchange experiences on substitution, concrete standards, long-term concrete performance of new cements, and environmental and economic impacts.

4. Facilitate the development of carbon capture and storage

Carbon capture and storage (CCS) is currently the most feasible new technology option to reduce CO_2 emissions in the cement industry and urgent action is needed to support its development and implementation. R&D, pilot projects and industrial-scale demonstration on effective CO_2 capture in

7 "Non-CEM I" are all common cements except for Ordinary Portland Cement according to the European standard EN 197-1. These cements have a lower clinker content than Ordinary Portland Cement.

the cement industry must be incentivised and put into action in the short term to enable full-scale capture to take place in the cement industry. This will support the full CCS chain.

The marginal abatement cost of CCS is estimated at USD40–170/t CO_2[8] abated (IEA, 2009), and its implementation would result in a doubling of cement costs. Without a global framework, implementation of this technology will only be possible if political frameworks effectively limit the risk of carbon leakage (see glossary). As the cost of CCS implementation will be lower for new installations than for retrofitting existing facilities, and as the majority of future demand will be in regions with no current carbon constraints, incentives must be in place to encourage the early deployment of CCS in all regions.

This roadmap recommends:

- Developing regulatory frameworks for CCS and international collaboration on CCS regulation e.g., the Support to Regulatory Activities for Carbon Capture and Storage (STRACO$_2$) project is designed to support the development of a regulatory framework for CCS in the European Union (www.euchina-ccs.org).
- Government support for funding of cement industry pilot and demonstration projects, leading to commercial-scale demonstration plants and storage site accessibility.
- Identifying and demonstrating transport networks and storage sites near cement plants.
- Coordinating CO_2 transport networks on a regional, national and international level to optimise infrastructure development and to lower costs.
- Investigating linkages into existing or integrated networks and opportunities for cluster activities in industrial zones.
- Government and industry significantly expanding efforts to educate and inform key stakeholders about CCS.

8 Includes transport and storage costs.

5. Encourage policies for predictable, objective and stable CO_2 constraints and energy frameworks on an international level

Until a global carbon price exists, or until there is clarity on if and when this may occur, industry is unable to plan effectively for technology R&D. Carbon markets must be linked to mechanisms that effectively engage industry in adopting cleaner technologies for emissions reductions. International climate change negotiations should be supported by agreements like sectoral approaches to industry emissions reductions or nationally appropriate mitigation actions (NAMAs).

This roadmap recommends:

- Modifying the current Clean Development Mechanism (CDM) framework to facilitate the funding of energy efficiency projects, and the inclusion of CCS projects, and accepting credits from CCS in emissions trading schemes such as EU ETS. Ensuring that policies, with supportive Monitoring, Reporting and Verification (MRV) frameworks, incentivise CCS technology through CDM. A global CDM fund could be developed, for which CCS would be eligible (and assist the commercial viability of CCS in the medium to long term), or CDM project criteria could include sectoral benchmarking within the cement industry, in which CDM gives incentives to early CCS development.
- Recognising the capture of biogenic CO_2 as a neutral emission, given the expected high share of biomass fuel use in the cement industry.
- Both rewarding clean energy investments, for example fiscal incentives for waste heat recovery, and penalizing poor energy investments, for example reducing subsidies if energy generation is inefficient.
- Government-industry collaboration within the UNFCCC process to explore key elements for successful frameworks e.g., sector data requirements; Measurement, Reporting and Verification (MRV) practices; target-setting, and potential crediting mechanisms based on a common calculation method for CO_2 emissions as stipulated by an international standard.
- Government and industry jointly defining effective national policy measures to help reduce cement industry CO_2 emissions and ensuring fair distribution of responsibilities

between government and industry. Local and regional action must be guided by good coordination with trade associations.

- Ensuring that the global political framework effectively limits the risk of carbon leakage.

6. Enhance research and development (R&D) capabilities, skills, expertise and innovation

A significant increase in R&D over the very long term is needed in the cement industry. Investment along the whole chain of innovation, from college-level training to industrial-scale innovation, must come from academia, from the industry, from equipment suppliers and from governments. For example, a new generation of hydraulic binders could provide high emissions reductions, but are not yet well understood or developed at scale and need further R&D focus.

This roadmap recommends:

- Increasing the number and skills level of scientific researchers with cement industry expertise, by joint support from industry and government for appropriate university programmes and by creating teaching and research positions on materials science and industry climate protection.
- Integrating or aligning research programmes at national and international levels and directly involving companies in programmes in those countries in which they operate.
- Encouraging joint scientific and engineering research projects between countries, and establishing collaborative research programmes or networks amongst companies, equipment suppliers, research institutes and governments to pool R&D funding and resources.
- Promoting the elaboration of standards that include a new generation of emerging cements, i.e., hydraulic binders, to foster fast uptake of cements with high potential for enabling emissions reductions.

7. Encourage international collaboration and public-private partnerships

Existing international knowledge in all areas of this roadmap must be evaluated and core knowledge integrated into a common goal: full-scale global implementation for emissions reductions technology. International collaboration has an important role to play as a catalyst in accelerating technological progress in the demonstration phase. In particular, the delivery of critical CCS facilities by 2020 lies far beyond the financial and technical capacity of individual companies or countries, and so requires large-scale cooperation at all stages.

New forms of public-private partnerships must be defined in which governments, R&D institutions, the cement industry, and equipment suppliers work together to organise, fund, screen, develop and demonstrate selected technologies in shorter time frames. A good example from the steel industry is the "Ultra–Low CO_2 Steelmaking (ULCOS)" project. This is a consortium of 48 European companies and organisations, financially supported by the European Commission, undertaking cooperative R&D research into CO_2 emissions reductions from steel production.

This roadmap recommends:

- Creating public-private partnerships that help minimise technological risks and create options to increase energy efficiency or reduce CO_2 emissions, for example the GTZ-Holcim Public Private Partnership coordinated by the University of Applied Sciences Northwestern Switzerland (www.coprocem.org).
- Ensuring international collaboration for CCS demonstration plants in the cement industry.
- Shifting national innovation priorities to ensure that international collaboration on research and development (R&D) activities around climate protection is effective at the scale and pace needed.
- Adapting technology transfer processes to individual regions, recognising that differences exist in availability of supply (raw materials, alternative fuels, clinker substitutes), legislative support and enforcement and in public understanding of cement manufacture processes.

A sectoral approach to emissions reductions

In the absence of a global agreement on emissions reductions, a sector-based analysis of the climate challenge, a sectoral approach, could offer various advantages over geographically organized responses. Because of this, sectoral approaches are now on the international climate policy agenda. For the CSI, a sectoral approach involves organized action by key producers in a specific industry, and their host governments to address the greenhouse gas emissions from their products and processes, within the UNFCCC framework. It can be implemented as part of nationally appropriate mitigation strategies (NAMAs). To show the relative impact of different policy choices on CO_2 emissions, the CSI undertook an economic and policy modeling project, coupled with stakeholder dialogues. An economic model was built featuring eight world regions and including data on production technology, shipping, energy costs and CO_2 abatement options. The model includes the regional goals and costs of carbon reduction options as well as trade. Different carbon policy choices can be analysed and compared, looking at impacts on regional CO_2 and cement flows and costs.

A sectoral approach was modeled as a combination of fixed emission limits (caps) in Annex I countries, with emissions efficiency goals in non-Annex I countries – only one of a number of possible policy combinations. Unlike other reports on the same topic, the CSI sectoral approach model does not make forecasts about the future. Instead, it compares different policy options with a "no commitments" base case. Model projections[9] indicate that:

- A sectoral approach could reduce cement industry emissions significantly compared to the base case.
- While regional differences exist, a sectoral approach could significantly increase access to the industry's major greenhouse gas mitigation levers by careful national policy design.
- Reaching the full potential of the sectoral approach requires supportive government policies in participating countries (for example covering cement standards, building codes, and waste management practices).

For most governments, a sectoral approach offers significant national control to tailor management of emissions and efficiency goals to local circumstances and capabilities. A sectoral approach could help improve the speed and effectiveness of industry's greenhouse gas mitigation efforts. If properly designed, it could offer strong participation incentives to developing economies, businesses and governments.

The CSI is ready, willing and able to collaborate on defining such an approach in more detail, including industry data requirements, Measurement, Reporting and Verification (MRV) practices, goal-setting and crediting policies, and targeted national policies, for example around cement product standards and construction codes.

The challenge for policy-makers is to turn current concepts around sectoral approaches into effective international policy instruments that will foster the rapid, cost-effective deployment of best available technology, and provide a strong signal to industry to make emissions mitigation a priority for innovation.

Recent work undertaken for the European Commission illustrates the political acceptability of various options, as well as the conditions that need to be met if a sectoral crediting mechanism is to be effective (CCAP et al., 2008). Other work has explored the process of arriving at feasible sectoral approaches under the UNFCCC regime (Baron et al., 2008; Ward et al., 2008). Separately, Japan's submission to the UNFCCC Poznan meeting on sectoral approaches has identified a number of steps that are needed for their successful implementation.[10]

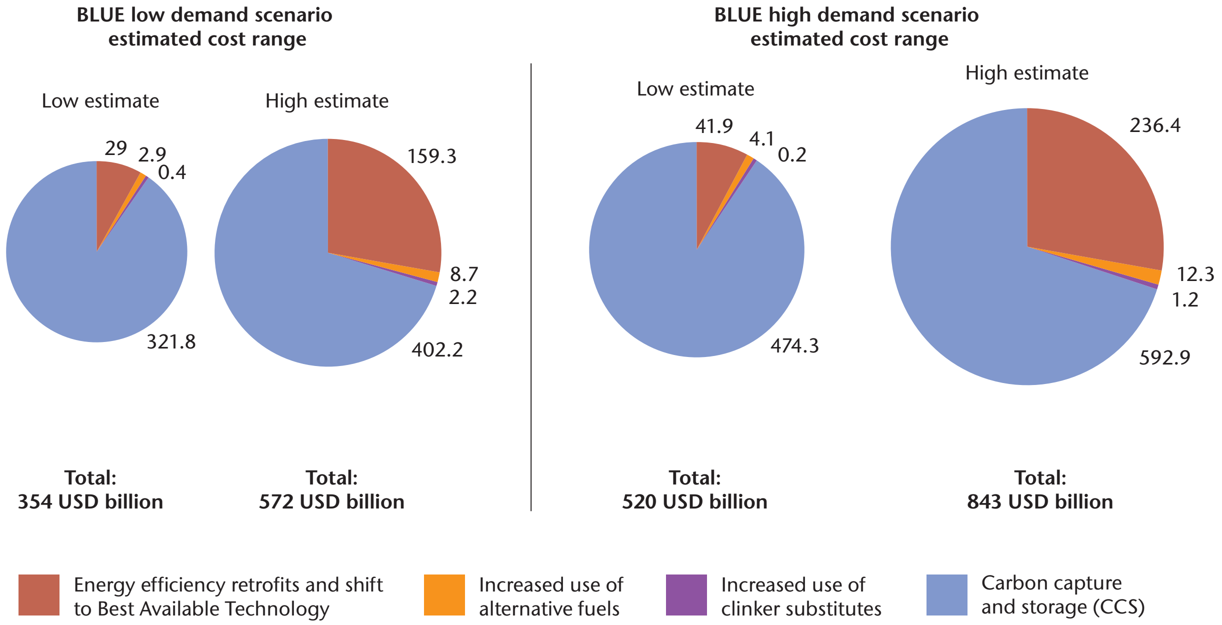
9 www.wbcsdcement.org/sectoral

10 Japan's Submission on Application of Sectoral Approaches – memorandum, November 2008

What financial support is needed?

Estimated Cumulative Additional Investment Needs in the BLUE Scenarios

Incremental cost (above Baseline) in USD billion



This report calculates the additional investment needs from 2005 to 2050 as the difference in technological investment between the business as usual scenario and the BLUE scenarios. The estimate does not include the economic benefits that these investments will produce that would lead to reduced investment costs.

Source: IEA, 2009

The IEA estimates that the additional investment cost to achieve a reduction in CO_2 emissions is in the range of USD350-570 billion under a low demand scenario and USD520-840 billion under a high demand scenario. Much of the additional investments will be needed in developing countries where CO_2 policies are now emerging. Overcoming barriers posed by limited capital and multiple demands for its use in developing economies related to widespread technology implementation will be critical.

Unlike the power industry, where higher costs for decarbonisation can be passed to the end user via the government-regulated rate-setting process, the price of cement is set by the market because cement is an internationally traded commodity. A global system of emissions trading may be another crucial policy instrument in the future. However, in the short to medium term, international agreements between all major producing countries covering the main energy-intensive industries could be a practical first step in stimulating the deployment of new technologies while addressing concerns about competitiveness and carbon leakage. For financing of energy efficiency improvements, government-guaranteed loans would support some countries in emissions reductions in the short term.

Investment needs for the cement industry are dominated by the additional up-front costs of CCS installations at cement plants. CCS in Europe could double the investment needs for a cement plant (ECRA, 2009), as well as increase energy use and operating costs. Clearly, the total investment needs and marginal abatement costs for the cement industry are critically sensitive to the future costs of CCS. In the short term, CCS development and demonstration will require strong government support as industry cannot bear these costs alone. An estimated USD2-3 billion is required to fund CCS demonstration projects in the cement industry and an additional USD30-50 billion will be needed by 2030 for deployment (representing 50-70 commercial plants).

Financial support will particularly be needed to develop and demonstrate cement industry carbon capture technologies. Before 2020, funding is needed for CCS demonstration plants, and later for oxyfuel demonstration. Traditional financing criteria used by industry would not support CCS projects unless a global carbon price (or incentive) is in place that provides a clear, long term signal for a value of CO_2 emissions reductions that justifies the cost of mitigating them. Unlike energy efficiency technologies that show a return on investment through reduced fuels costs, carbon capture technologies do not currently offer returns. In fact, they are likely to raise operating costs. A long term global carbon price of USD50-100 per tonne of CO_2, rising to USD200/tonne by 2050 is likely to be needed to provide returns on CCS investments.

In the near term, it is unlikely that the funding gap associated with the incremental cost of CCS will be covered by existing CO_2 markets. Accordingly, governments will be required to contribute to meeting this funding gap, as without commercial drivers it is unlikely industry will cover this gap by itself. If no CO_2 incentive or penalty is put in place, additional R&D, co-funded with governments, and additional deployment support, will be needed.

For large-scale commercial deployment of CCS, a broader financing mechanism will be required. Mechanisms will need to provide long term certainty of a sufficiently high CO_2 price level. Without such a mechanism, CCS will not be deployed at the level required to meet the roadmap's objectives. This will require the strengthening of existing CO_2 abatement financing mechanisms (e.g., ensuring CCS is eligible for CDM projects) and the creation of new mechanisms such as a guaranteed minimum price for CO_2 captured and stored. The most commonly considered funding mechanism for CO_2 abatement is a cap-and-trade system such as the EU Emissions Trading Scheme.

Various funding sources are currently available within different countries to develop and deploy low-carbon technologies, but most focus on energy efficiency and few are at the scale needed to finance CCS development and deployment. Funding for CCS demonstration is currently focused on power generation, but should be expanded to include CCS demonstration in cement and other industries as there are significant differences between industries in applying this technology. A share of the funding from the economic stimulus packages dedicated for CCS should be allocated to the cement industry.

Overall, the current financial crisis, a weak economic outlook, and decreases in commodity prices have significantly changed the cement industry's investment timetable. New projects have been delayed or cancelled due to a lack of (affordable) construction funding and uncertainty around future demand. Under this economic environment, it will be crucial for governments to support technology development in tangible ways, for example, through widespread government loan guarantees to help lower investment risks in low-carbon technologies.

This roadmap recommends:

- A global emissions trading system that would help minimise costs of CO_2 reduction options in the cement industry at least cost, including CCS.
- Ear-marking government loan guarantees to help minimise risks and ensure CCS investments in the cement industry are financeable.
- Expansion of the Clean Development Mechanism to and Joint Implementation projects facilitate the funding of energy efficiency, alternative fuel and clinker substitution projects, and CCS in the cement industry.
- Wide promotion of alternative sources of funding for low-carbon technologies in the cement industry, including export credit agencies and multilateral development banks (e.g., Climate Investment Funds administered by the World Bank, International Finance Corporation, European Bank for Reconstruction and Development, European Investment Bank) and energy services companies.

Progress indicators

Indicators have been identified to help track progress against the cement roadmap. It is difficult to develop such indicators because technologies advance at different speeds and implementation of CO_2 intensity reduction options is unpredictable. They are nevertheless helpful in developing milestones for future technology and policy planning. The indicators cover implementation of best available technology, alternative fuels use, clinker substitution and CCS development, demonstration and deployment needs to 2050. These indicators aim to illustrate what developments are needed in the cement industry to achieve the targets set out in the roadmap. They can be used as a general guideline for setting targets under an international collaborative framework. The figures for CCS are ambitious given the current state of unproven technical and commercial viability, and highlight the urgent need for actions on the demonstration and deployment phases.

Cement Roadmap Indicators

	2012	2015	2020	2025	2030	2050
Thermal energy consumption per tonne of clinker GJ / tonne	3.9	3.8	3.5-3.7	3.4-3.6	3.3-3.4	3.2
Share of alternative fuel & biomass use (1)	5-10%	10-12%	12-15%	15-20%	23-24%	37%
Clinker to cement ratio	77%	76%	74%	73.5%	73%	71%
CCS						
no. of pilot plants	2	3				
no. of demo plants operating		2	6			
no. of commerical plants operating				10-15	50-70	200-400
Mt stored	0.1	0.4	5-10	20-35	100-160	490-920
Tonne CO_2 emissions per tonne cement (2)	0.75	0.66	0.62	0.59	0.56	0.42

Notes: (1) assumes 25 to 30 Mtoe of alternative fuel use in 2015 and 50 to 60 Mtoe in 2030, and excludes energy from CCS and electricity use, (2) includes reduction from CCS

Source: IEA, 2009

Stakeholder	Action Item (examples of such actions are given in the roadmap)
Finance / economy ministries	• Reward clean energy investments e.g., fiscal incentives for waste heat recovery (WHR) • Eliminate energy price subsidies that can act as a barrier to implementation of more energy efficient technologies • Provide government loan guarantees to support risk management and funding for CCS pilot and demonstration plants • Enable a global emissions trading system that facilitates the financing of CO_2 reduction options in the cement industry
Environmental, energy and resource ministries	• Share good practice policies for the promotion of energy efficiency and CO_2 emissions reduction • Develop and implement international standards for energy efficiency and CO_2 emissions • Ensure national waste disposal policies enable the full potential of co-processing in the cement industry and facilitate stakeholder and public understanding of the role of alternative fuel use in climate change mitigation • Develop new, or revise existing, cement standards and codes, to allow more widespread use of blended cement and facilitate the use of a new generation of emerging cements • Fund RD&D programmes to target knowledge gaps on different aspects of CCS technology development/co-development • Modify the CDM framework to facilitate the funding of energy efficiency projects and the inclusion of CCS projects • Accept credits from CCS in emissions trading schemes e.g., EU ETS • Develop regulatory frameworks for CCS and international collaboration on CCS regulation • Establish CCS outreach/education programmes for the general public • Investigate linkages into existing or potential integrated networks and opportunities for CCS cluster activities in industrial zones, and identify transport networks and storage sites near cement plants
Training/science ministries and universities	• Promote international training events with national standardisation bodies and accreditation institutes to exchange experiences on substitution, concrete standards, concrete performance • Oversee independent Environmental Impact Studies (EIS) on use of key substitution materials by the cement and other industries to show where to achieve the highest potential emissions reductions • Increase the number and skills level of scientific researchers with cement industry expertise by creating teaching and research positions on materials science and industry climate protection • Integrate or align climate protection research programmes at national and international levels and directly involve companies where possible • Create institutional frameworks for industry-scale technology initiatives (managing and implementing projects, financing mechanisms, partnership rules, governance models), in collaboration with other stakeholders, to foster cooperation between countries and their public and private sectors to pool funding and knowledge, and join complementary skills
MDAs*	• Promote alternative sources of funding for low-carbon technologies in the cement industry including export credit agencies, multilateral development banks
Industry	• Phase out long-dry kilns and wet production processes around the world • Gather reliable industry-level energy and emissions data to track performance and identify benchmarks • R&D into processing techniques for potential clinker substitutes that cannot currently be used due to quality constraints • Join discussions with governments on promotion of Industrial Ecology concepts and landfill mining to generate alternative fuels and raw materials • Establish collaborative research programmes or networks amongst companies, equipment suppliers, research institutes and governments to pool R&D resources, and public-private partnerships on emissions reductions (including on CCS) • Collaborate with government within the UNFCCC process to explore key elements of successful climate frameworks e.g., industry data requirements, MRV, target-setting and potential crediting mechanisms
State, provincial and local governments	• Review and update local legislation to ensure alternative fuel and biomass use is incentivised by policy and not restricted • Engage with cement industry trade associations to ensure fair distribution of responsibilities between government and industry around technology development • Ensure operators follow common sets of guidelines on alternative fuel use to guarantee adequate processes, e.g., training, documenting, monitoring for transparency • Provide adequate training for those responsible for permits, control and supervision to build trust among communities • Adapt technology transfer processes to individual regions, recognizing that differences exist in availability of supply, legislative support and enforcement, and public understanding
NGOs and think tanks	• Engage with the industry to fully understand the role of co-processing in climate protection • Communicate the role of CCS in climate change mitigation

*Multilateral development agencies

In conclusion

This roadmap is the first that focuses on an industry-wide approach to emissions reductions technology. The IEA and CSI member companies have worked together to develop a possible transition path for one industry moving towards the year 2050 with half the current CO_2 emissions.

Four key reduction levers available to the cement industry to reduce CO_2 emissions are discussed in this roadmap:

1. Thermal and electric efficiency
2. Alternative fuel use
3. Clinker substitution
4. Carbon capture and storage

Realizing the full potential of each lever requires political and economic support and technological development within the industry itself. Achieving the full results outlined in the roadmap requires the full complement of policy and technology actions described. Progress indicators indentified on page 24 will only be achieved with regional action appropriate to the potential of each reduction lever in each specific region. The broad policy recommendations should be tailored by different regions to ensure that an industry-wide approach to emissions reductions is compatible with regional differences, for example in material availability.

The vision for such reductions is ambitious. The roadmap has been designed with milestones to help the international community track technological development efforts to achieve the CO_2 emissions reductions required by 2050. Future updates of this roadmap will be required to reflect the real situation and monitor progress against the roadmap indicators.

We have developed this roadmap together to show the value of collaboration and partnership in achieving the deep emissions reductions required globally. We offer here one potential pathway for one industry. With this, we seek open dialogue with policy-makers, financial partners and other industries to help us all to adapt effectively to the carbon-constrained world we face in the years ahead.

For more information about the roadmap inputs and implementation, visit www.iea.org/roadmaps and for information on how the roadmap connects to other CSI work on climate protection and emissions reductions, visit www.wbcsdcement.org/technology.

Glossary

- **aggregates**: materials used in construction, including sand, gravel and crushed stone
- **alternative fossil fuels**: products from fossil fuel origin used as a source of thermal energy and not classified as traditional fossil fuel. This is mainly fossil waste such as plastics, solvents, waste oil, end-of-life tyres, etc.
- **biomass**: products from biogenic origin used as a source of thermal energy, including from animals or plants. This is mainly waste from agriculture, forestry, biologic waste water treatment and agro-industry
- **blended cement**: Portland cement mixed with clinker substitutes
- **carbon leakage**: an increase in CO_2 emissions in one country as a result of an emissions reduction in a second country, e.g., if that second country has a stricter climate policy
- **cement**: a building material made by grinding clinker together with various mineral components such as gypsum, limestone, blast furnace slag, coal fly ash and natural volcanic material. It acts as the binding agent when mixed with sand, gravel or crushed stone and water to make concrete. While cement qualities are defined by national standards, there is no worldwide, harmonised definition or standard for cement. In the WBCSD – CSI Protocol and the "Getting the Numbers Right" database, "cement" includes all hydraulic binders that are delivered to the final customer, i.e., including all types of Portland, composite and blended cements, plus ground granulated slag and fly ash delivered to the concrete mixers, but excluding clinker. See section 6.3 of the WBCSD – CSI Cement Protocol for the precise definition
- **cementitious products**: total of all cements and clinker produced by a cement company, excluding the clinker purchased from another company and used to make cement. The precise definition of cementitious product in this context is according to section 6.2 of the WBCSD – CSI Cement Protocol. Cement is equal to cementitious product when the net balance of clinker sold and purchased is zero
- **clinker**: intermediate product in cement manufacturing and the main substance in cement. Clinker is the result of calcination of limestone in the kiln and subsequent reactions caused through burning
- **co-processing**: the use of waste materials in industrial processes, e.g., cement, as a substitute for primary fuel or raw materials
- **CSI**: Cement Sustainability Initiative; see www.wbcsdcement.org
- **EU ETS**: European Union Emissions Trading System
- **fly ash**: exhaust-borne particulates generated and captured at coal-fired power plants
- **geopolymer cement**: cement manufactured with chains or networks of mineral molecules producing 80–90% less CO_2 than OPC; see www.geopolymer.org
- **GNR**: "Getting the Numbers Right" CSI's global cement database covering over 800 plants around the world belonging to the 18 CSI member companies
- **gross CO_2 emissions**: all direct CO_2 emissions (excluding on-site electricity production) excluding CO_2 emissions from biomass which are considered climate neutral
- **IEA**: International Energy Agency www.iea.org
- **membrane technology**: this technology involves membranes specifically manufactured to allow a selective passage for gas (e.g., CO_2). The process depends on the nature of the materials and the press difference across the membrane itself. These new gas-separation technologies have not yet been applied at industry-scale
- **MRV**: Monitoring, Reporting and Verification
- **NAMA**: nationally appropriate mitigation actions
- **Net CO_2 emissions**: gross CO_2 emissions minus emissions from alternative fossil fuels
- **Ordinary Portland Cement (OPC)**: most common type of cement, consisting of over 90% ground clinker and about 5% gypsum
- **petcoke**: petroleum coke, a carbon-based solid derived from oil refineries
- **pozzolana**: a material that, when combined with calcium hydroxide, exhibits cementitious properties
- **precalciner kiln**: a rotary kiln equipped so that most of the limestone calcination is accomplished in a separate apparatus ahead of the rotary kiln, more energy-efficient than having all of the calcination take place in the kiln itself
- **sectoral approach**: a combination of policies and measures developed to enhance efficient, sector by- sector greenhouse gas mitigation within the UN framework. Producers and their host country governments adopt a set of emissions goals, which may vary by country, or take other co-ordinated action to help combat climate change; see www.wbcsdcement.org/sectoral
- **technology roadmap**: roadmaps to support low-carbon industry, academic and research groups, civil society and governments to identify and prioritise the strategic R&D and investments needed to achieve technology development goals
- **traditional fuels**: fossil fuels defined by the International Panel on Climate Change (IPCC) guidelines, including mainly: coal, petcoke, lignite, shale, petroleum products and natural gas
- **WBCSD**: World Business Council for Sustainable Development www.wbcsd.org

References

For full references used throughout the roadmap, visit www.wbcsdcement.org/technology or www.iea.org/roadmaps/cement.asp

Annex I: Emissions factors used in roadmap model by IEA

CO_2 Emission Factor	
Coal	4.4 $MtCO_2$/mtoe
Oil	3.2 $MtCO_2$/mtoe
Gas	2.34 $MtCO_2$/mtoe
Alternative Fuels (average)	1.85 $MtCO_2$/mtoe
CCS Process	0.54 tCO_2/t clinker

Annex II: Calculation of the baseline used in roadmap model by IEA

	2006	Baseline 2050 (low)	Baseline 2050 (high)	Roadmap 2050 (low demand)	Roadmap 2050 (high demand)
GLOBAL INDICES					
% clinker	79	75	74	71	73
% alternative fuels (incl biomass)*	3	4	4	37	37
GJ/t clinker	4.2	3.5	3.5	3.3	3.2
kWh/t cement (excl CCS)	111	95	95	92	92
t CO_2 / t cement	800	693	636	426	352**
GLOBAL VOLUMES					
Cement production, million t	2,559	3,657	4,397	3,657	4,397
CO_2 emissions (excluding CCS), million t	2,047	2,337	2,796	2,052	2,521

*IEA uses 40% biomass in alternative fuels

**The low specific emissions in the high demand case, 352t CO_2/t cement, must be achieved to meet the IEA BLUE scenario. This requires the ambitious capture and storage of approximately 221kg CO_2 per tonne of cement produced in 2050.

The roadmap forecasts significant reductions in emissions coming from baseline developments within the cement industry. These include reductions in the percentage of clinker in cement and in energy consumption, from both kiln fuel and electricity. Coupled with a small increase in alternative fuel use, this will reduce specific emissions from a current level of 800 to 693kg CO_2 per tonne cement (a reduction of just over 13%).

Annex III: Key differences between low and high cement demand scenarios

Cement demand forecast is a crucial parameter to assess potential emissions reductions. A higher demand will imply either lower absolute reductions achievable over time, faster implementation of CCS, or a combination of both. A range of forecasts are found in different studies undertaken, and the IEA forecast for 2050 demand used in this roadmap is at the lower end of the range of forecasts found. For example, IDDRI and Entreprises pour l'Environnement (EpE) forecast 2050 cement demand at nearly 5 billion tonnes, and WWF/Lafarge forecast over 5.5 billion tonnes (see references). This list outlines key differences between the low and high scenarios modeled by the IEA:

- Low demand scenario forecasts 2050 production of 3.66 billion tonnes and high demand scenario forecasts 4.4 billion tonnes of production, i.e.: **0.74 billion tonnes difference**
- **CO_2 abatement from CCS**: 0.43 Gt difference between low and high scenarios
- **CO_2 abatement without CCS**: 0.42 Gt difference between low and high scenarios
- **Total CO_2 abated**: 0.01 Gt difference between low and high scenarios
- **Emissions intensity (including CO_2 from electricity use)**: 0.074 t CO_2 / t cement difference between low and high scenarios
- **Emissions intensity (excluding CCS)**: 0.003 t CO_2 / t cement
- **Electricity use**: no difference between low and high scenarios excluding CCS. 14 kWh/t cement difference including CCS

ABOUT THE IEA

The International Energy Agency (IEA) is an autonomous body which was established in November 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme.

It carries out a comprehensive programme of energy co-operation among twenty-eight of the thirty OECD member countries. The basic aims of the IEA are:

- To maintain and improve systems for coping with oil supply disruptions.
- To promote rational energy policies in a global context through co-operative relations with non-member countries, industry and international organisations.
- To operate a permanent information system on international oil markets.
- To provide data on other aspects of international energy markets.
- To improve the world's energy supply and demand structure by developing alternative energy sources and increasing the efficiency of energy use.
- To promote international collaboration on energy technology.
- To assist in the integration of environmental and energy policies, including relating to climate change.

IEA member countries: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Korea (Republic of), Luxembourg, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom and United States, The European Commission also participates in the work of the IEA.

The OECD is a unique forum where the governments of thirty democracies work together to address the economic, social and environmental challenges of globalisation.

The OECD is also at the forefront of efforts to understand and to help governments respond to new developments and concerns, such as corporate governance, the information economy and the challenges of an ageing population. The Organisation provides a setting where governments can compare policy experiences, seek answers to common problems, identify good practice and work to co-ordinate domestic and international policies.

www.iea.org

International Energy Agency

ABOUT THE WBCSD

The World Business Council for Sustainable Development (WBCSD) brings together some 200 international companies in a shared commitment to sustainable development through economic growth, ecological balance and social progress. Our members are drawn from more than 36 countries and 22 major industrial sectors. We also benefit from a global network of about 60 national and regional business councils and partner organizations.

Our mission is to provide business leadership as a catalyst for change toward sustainable development, and to support the business license to operate, innovate and grow in a world increasingly shaped by sustainable development issues.

Our objectives include:

- Business Leadership – to be a leading business advocate on sustainable development
- Policy Development – to help develop policies that create framework conditions for the business contribution to sustainable development
- The Business Case – to develop and promote the business case for sustainable development
- Best Practice – to demonstrate the business contribution to sustainable development and share best practices among members
- Global Outreach – to contribute to a sustainable future for developing nations and nations in transition.

www.wbcsd.org

World Business Council for Sustainable Development

ABOUT THE CSI

The Cement Sustainability Initiative (CSI) is a global effort by 18 leading cement producers. Headquartered in 14 countries, they have operations in more than 100 countries. Collectively, these companies account for about 30% of the world's cement production and range in size from very large multinationals to smaller local producers. All CSI members have integrated sustainable development into their business strategies and operations, as they seek strong financial performance with an equally strong commitment to social and environmental responsibility. Over its 10-year history, the CSI has focused on understanding, managing and minimizing the impacts of cement production and use by addressing a range of issues, including: climate change, fuel use, employee safety, airborne emissions, concrete recycling and quarry management.

www.wbcsdcement.org

Cement Sustainability Initiative

DISCLAIMER

This report is the result of a collaborative effort between the International Energy Agency (IEA) and the WBCSD Cement Sustainability Initiative (CSI). It has been developed in close consultation with a broad range of stakeholders. Input has been provided by the IEA, CSI member companies and the cement industry, equipment suppliers, academic institutions and companies working on cement technology innovation. External stakeholders were consulted on the technology papers and the roadmap draft, and this document reflects input received. The individual member companies that make up the CSI, and their subsidiaries, have participated in the development of this roadmap in strict compliance with applicable competition laws. No specific commitments on implementation of any technologies described in the report have been made. Users of this report shall make their own independent business decisions at their own risk and, in particular, without undue reliance on this report.

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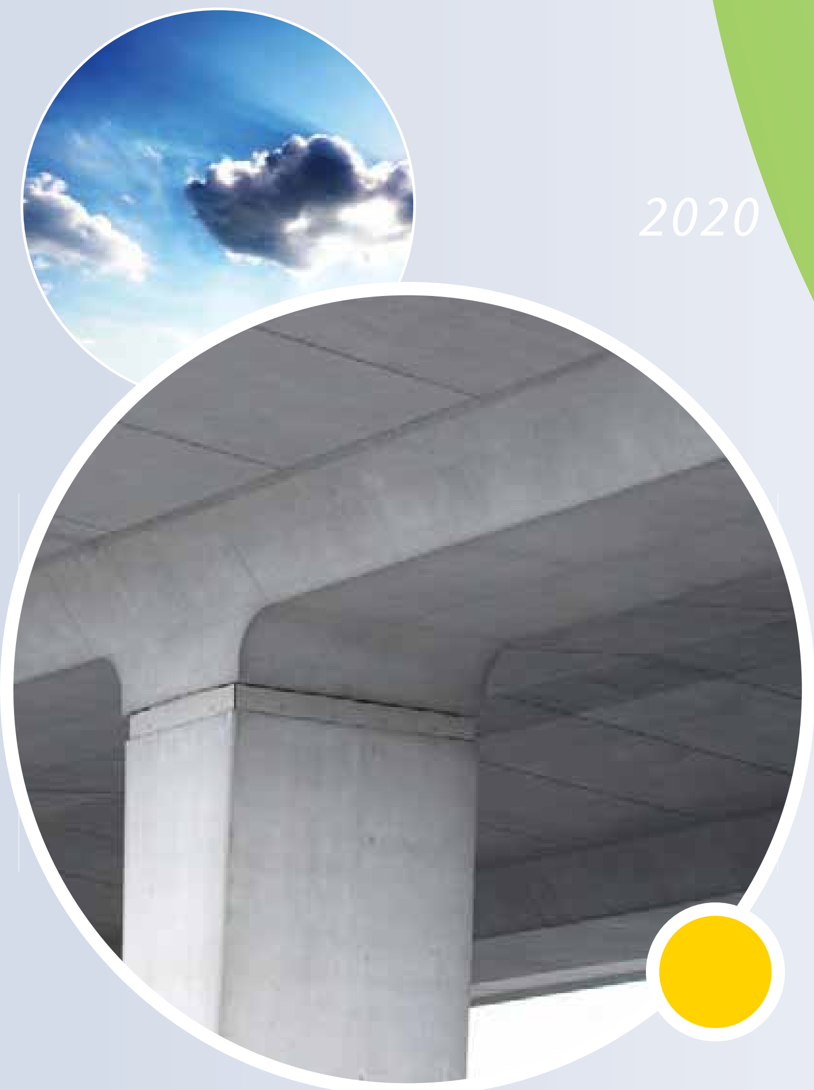
Cement Technology Roadmap 2009 Carbon emissions reductions up to 2050

2010

2015

2020



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Key regional milestones

This roadmap aims to propose tangible policy recommendations for governments around the world and so is written with a broad, global view

However, it acknowledges the wide differences between regions for many aspects of cement industry technology development and implementation. There are differences, for example, in alternative fuel availability, and in building standards enabling or preventing higher clinker substitution

It is key that nationally appropriate policies should be developed to reinforce this roadmap's broad recommendations

Alternative fuel shares presented exclude the additional energy requirement for CCS

The CO_2 storage figures presented here are based on capture potentials. Additional analysis is needed to verify the storage potential in different regions

Canada and United States

	BLUE low demand			BLUE high demand		
Technologies	**2015**	**2030**	**2050**	**2015**	**2030**	**2050**
Energy use (Mtoe)	12.4	11.4	12.3	12.2	11.3	14.2
Share of alternative fuel use	8%	21%	37%	9%	22%	38%
Clinker to cement ratio	0.90	0.85	0.81	0.90	0.84	0.81
CO_2 captured (Mt)	0	4.9	21.5	0	9.3	43.0

European Union 25

	BLUE low demand			BLUE high demand		
Technologies	**2015**	**2030**	**2050**	**2015**	**2030**	**2050**
Energy use (Mtoe)	15.5	13.3	13.7	16.5	15.7	19.0
Share of alternative fuel use	17%	28%	39%	18%	30%	40%
Clinker to cement ratio	0.76	0.73	0.69	0.76	0.72	0.71
CO_2 captured (Mt)	0	4.3	20.7	0	9.4	69.8

Other OECD Europe

	BLUE low demand			BLUE high demand		
Technologies	**2015**	**2030**	**2050**	**2015**	**2030**	**2050**
Energy use (Mtoe)	2.7	3.3	3.9	2.9	3.9	5.4
Share of alternative fuel use	19%	30%	39%	21%	30%	40%
Clinker to cement ratio	0.82	0.80	0.80	0.78	0.72	0.73
CO_2 captured (Mt)	0	1.7	5.5	0	4.6	3.7

OECD Pacific

	BLUE low demand			BLUE high demand		
Technologies	**2015**	**2030**	**2050**	**2015**	**2030**	**2050**
Energy use (Mtoe)	9.7	8.2	7.5	10.3	9.5	10.7
Share of alternative fuel use	12%	23%	35%	13%	24%	35%
Clinker to cement ratio	0.83	0.77	0.72	0.82	0.76	0.72
CO_2 captured (Mt)	0	4.0	15.8	0	7.2	38.2

China

	BLUE low demand			BLUE high demand		
Technologies	**2015**	**2030**	**2050**	**2015**	**2030**	**2050**
Energy use (Mtoe)	118.2	66.1	53.3	118.8	85.6	76.9
Share of alternative fuel use	8%	20%	36%	8%	14%	34%
Clinker to cement ratio	0.72	0.69	0.68	0.71	0.69	0.70
CO_2 captured (Mt)	0	25.0	82.0	0	40.3	236.8

India

	BLUE low demand			BLUE high demand		
Technologies	**2015**	**2030**	**2050**	**2015**	**2030**	**2050**
Energy use (Mtoe)	19.4	29.9	47.4	19.6	33.6	60.1
Share of alternative fuel use	13%	23%	33%	15%	27%	35%
Clinker to cement ratio	0.77	0.73	0.71	0.77	0.72	0.72
CO_2 captured (Mt)	0	23.7	99.8	0	28.8	173.1

Other developing Asia

	BLUE low demand			BLUE high demand		
Technologies	**2015**	**2030**	**2050**	**2015**	**2030**	**2050**
Energy use (Mtoe)	24.7	35.1	51.2	26.3	39.4	64.5
Share of alternative fuel use	11%	21%	34%	15%	28%	35%
Clinker to cement ratio	0.78	0.72	0.70	0.78	0.72	0.73
CO_2 captured (Mt)	0	21.4	100.2	0	21.0	150.6

Economies in transition

	BLUE low demand			BLUE high demand		
Technologies	**2015**	**2030**	**2050**	**2015**	**2030**	**2050**
Energy use (Mtoe)	14.7	12.7	10.8	17.9	15.2	16.2
Share of alternative fuel use	14%	22%	35%	7%	16%	37%
Clinker to cement ratio	0.77	0.74	0.72	0.77	0.74	0.72
CO_2 captured (Mt)	0	1.5	12.9	0	4.1	19.0

Latin America

	BLUE low demand			BLUE high demand		
Technologies	**2015**	**2030**	**2050**	**2015**	**2030**	**2050**
Energy use (Mtoe)	14.5	18.4	26.4	14.4	18.5	32.7
Share of alternative fuel use	16%	25%	39%	16%	25%	40%
Clinker to cement ratio	0.73	0.71	0.70	0.73	0.71	0.72
CO_2 captured (Mt)	0	9.7	49.7	0	11.8	73.3

Africa and Middle East

	BLUE low demand			BLUE high demand		
Technologies	**2015**	**2030**	**2050**	**2015**	**2030**	**2050**
Energy use (Mtoe)	25.5	30.5	47.0	26.4	35.3	68.0
Share of alternative fuel use	11%	22%	33%	14%	25%	35%
Clinker to cement ratio	0.82	0.77	0.74	0.81	0.76	0.76
CO_2 captured (Mt)	0	8.4	97.1	0	21.5	158.7

Global cement production 2006 (total 100%)

Regional cement production

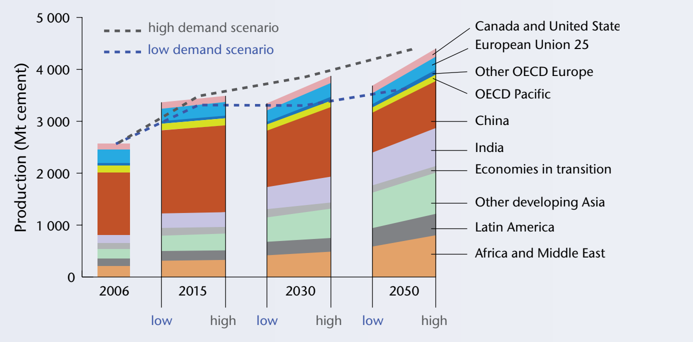
This map and figures show estimated cement production for the years 2006, 2015, 2030 and 2050, and regional breakdown of forecast production under BLUE high and low demand scenarios

Between 2006 and 2050, cement production is projected to grow by 0.8-1.2% per year, reaching between 3,700 megatonnes (Mt) and 4,400 Mt in 2050. This represents a 43-72% increase compared to production in 2006

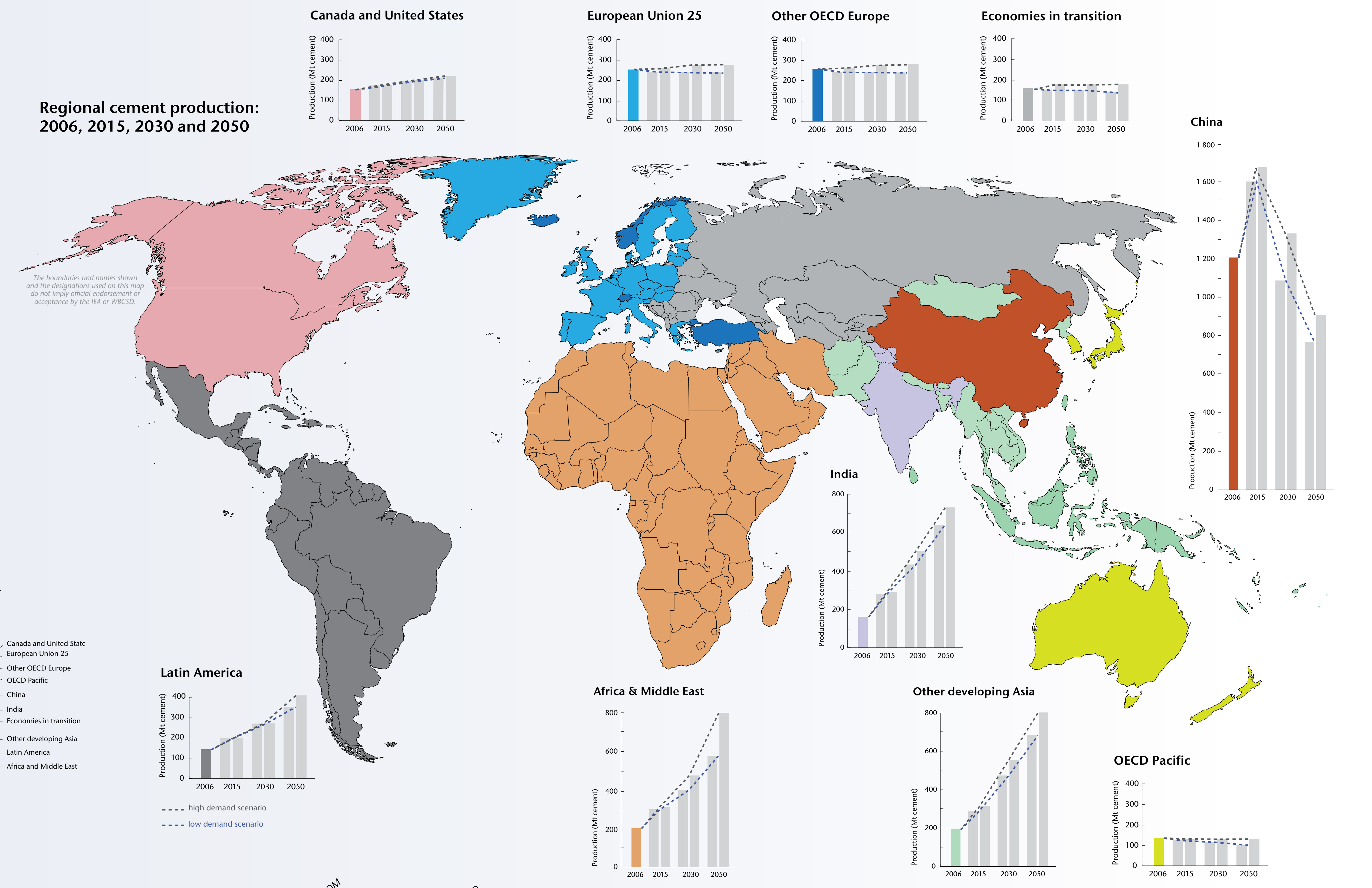
Cement consumption in China, which currently accounts for just under half of total production, is expected to peak between 2015 and 2030, as per capita cement consumption declines towards more developed country levels

Post-2030 global cement production will be fuelled by strong demand growth in India and other developing Asian countries, and in Africa and the Middle East

Global cement production: 2006, 2015, 2030 and 2050



Regional cement production: 2006, 2015, 2030 and 2050

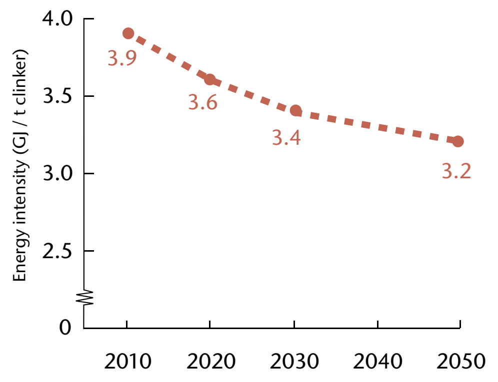


Cement roadmap targets

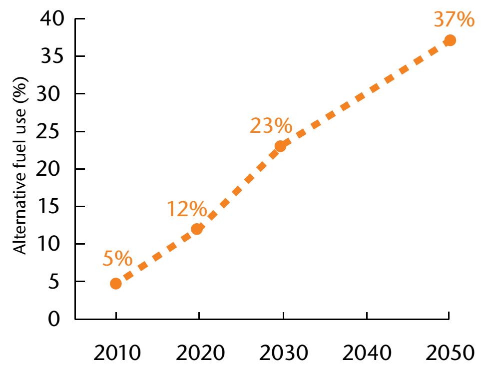
2010 | 2020 | 2030 | 2040 | 2050

This timeline is based on a set of 38 technology papers developed by the European Cement Research Academy (ECRA) on behalf of CSI, and on IEA modeling and scenario analysis

Targets for decrease in energy intensity, 2010-2050

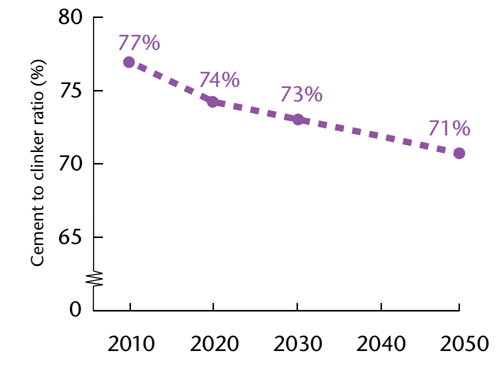


Targets for alternative fuel use, 2010-2050



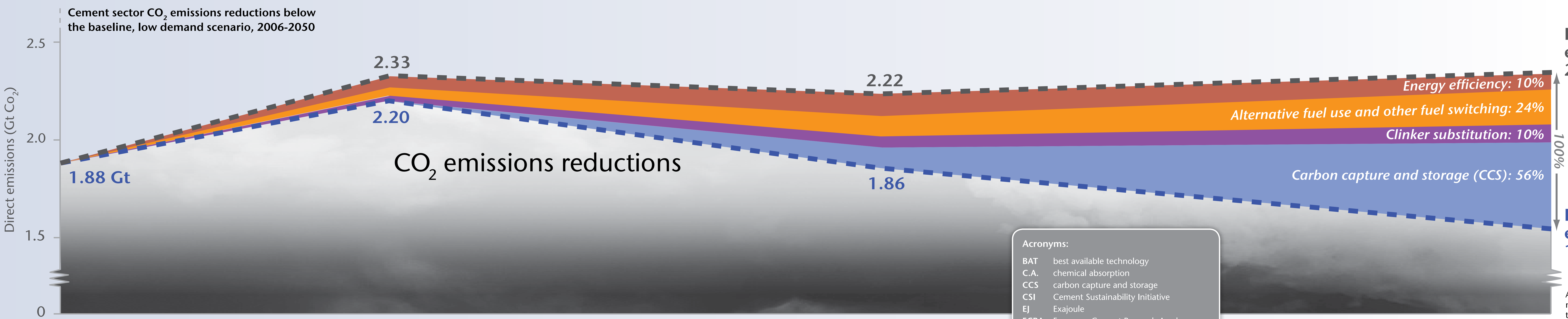
Note: excludes CCS energy use and electricity

Targets for decrease in cement to clinker ratio, 2010-2050



Note: all figures show global average

Cement sector CO_2 emissions reductions below the baseline, low demand scenario, 2006-2050



Baseline emissions: 2.34 Gt

Opportunities for CO_2 emissions reductions

BLUE emissions: 1.55 Gt

All of these technologies need to be applied together if the BLUE scenario targets are to be achieved – no one option alone can yield the necessary emissions reductions

The BLUE scenario examines the implications of a policy objective to halve global energy-related CO_2 emissions in 2050 compared to today's level

The outcomes implicit in the BLUE scenario are consistent with a global rise in temperatures of 2°C to 3°C, but only if the reduction in energy-related CO_2 emissions is combined with deep cuts in other greenhouse gas (GHG) emissions

A halving of global emissions will mean that the cement industry will need to reduce its current emissions by 18% by 2050

Acronyms:

BAT	best available technology
C.A.	chemical absorption
CCS	carbon capture and storage
CSI	Cement Sustainability Initiative
EJ	Exajoule
ECRA	European Cement Research Academy
GJ	Gigajoule
Gt	Gigatonne
IEA	International Energy Agency
OECD	Organisation for Economic Cooperation and Development
R&D	research and development
tCO_2	tonne of CO_2

Energy efficiency

- R&D on fluidised bed technology
- R&D into new grinding equipment and additives
- *Diffusion of BAT:* phase out of wet kilns in OECD
- *Diffusion of BAT:* international standard for new kilns
- *Diffusion of BAT:* phase out of wet kilns in non-OECD
- *Diffusion of BAT:* global energy intensity 3.2-3.4 Gt / t clinker
- *Diffusion of BAT:* global energy intensity 3.1-3.2 Gt/t clinker

Alternative fuel use and fuel switching

- Ongoing identification and classification of suitable alternative fuels

Clinker substitution

- Assess substitution material properties and evaluate regional availability
- Develop international standards on blended cement use
- Implement international standards on blended cement use
- *Cement to clinker ratio: 73%*
- *Cement to clinker ratio: 71%*

Carbon capture and storage (CCS)

R&D - oxyfueling, gas cleaning: 1[st] CCS pilot plant

R&D - oxyfueling, gas cleaning: develop oxyfueling and chemical looping

Demonstration: 2 chemical absorption demonstration plants

Mitigation costs USD/tCO_2 cement (post combustion/oxyfueling): 125/na

Demonstration: 3 oxyfuel demos, 3 chemical looping demos

R&D - oxyfueling, gas cleaning: C.A. energy use to fall to 2.2 GJ/t

Deployment: all large new kilns with CCS

Mitigation costs USD/tCO_2 cement (post combustion/oxyfueling): 100/60

Commercial use of membrane technology

Deployment: 50-70 cement kilns with CCS

Mitigation costs USD/tCO_2 cement (post combustion/oxyfueling): 100/50

Gt captured: 0.11-0.16 Gt; ***% CO_2 captured:*** 10-12%

Deployment: 100-200 cement kilns with CCS

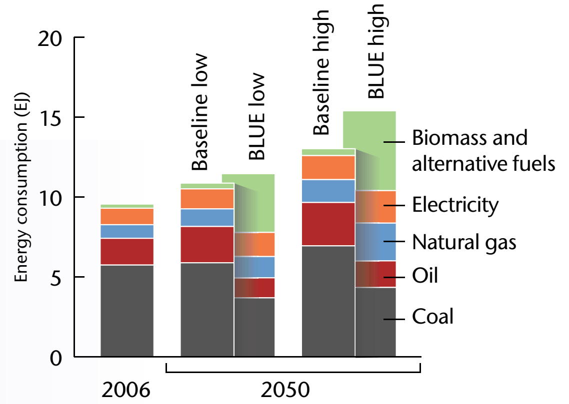
Deployment: 220-430 cement kilns with CCS

Mitigation costs USD/tCO_2 cement (post combustion/oxyfueling): 75/40

Gt captured: 0.5-1.0 Gt ; ***% CO_2 captured:*** 40-45%

Research and development (R&D) | *Demonstration* | *Deployment* | *Commercialisation*

Final energy consumption in the cement sector by scenario, 2006 and 2050



The application of CCS increases energy use and hence in the BLUE scenarios energy use rises compared to the Baseline scenarios