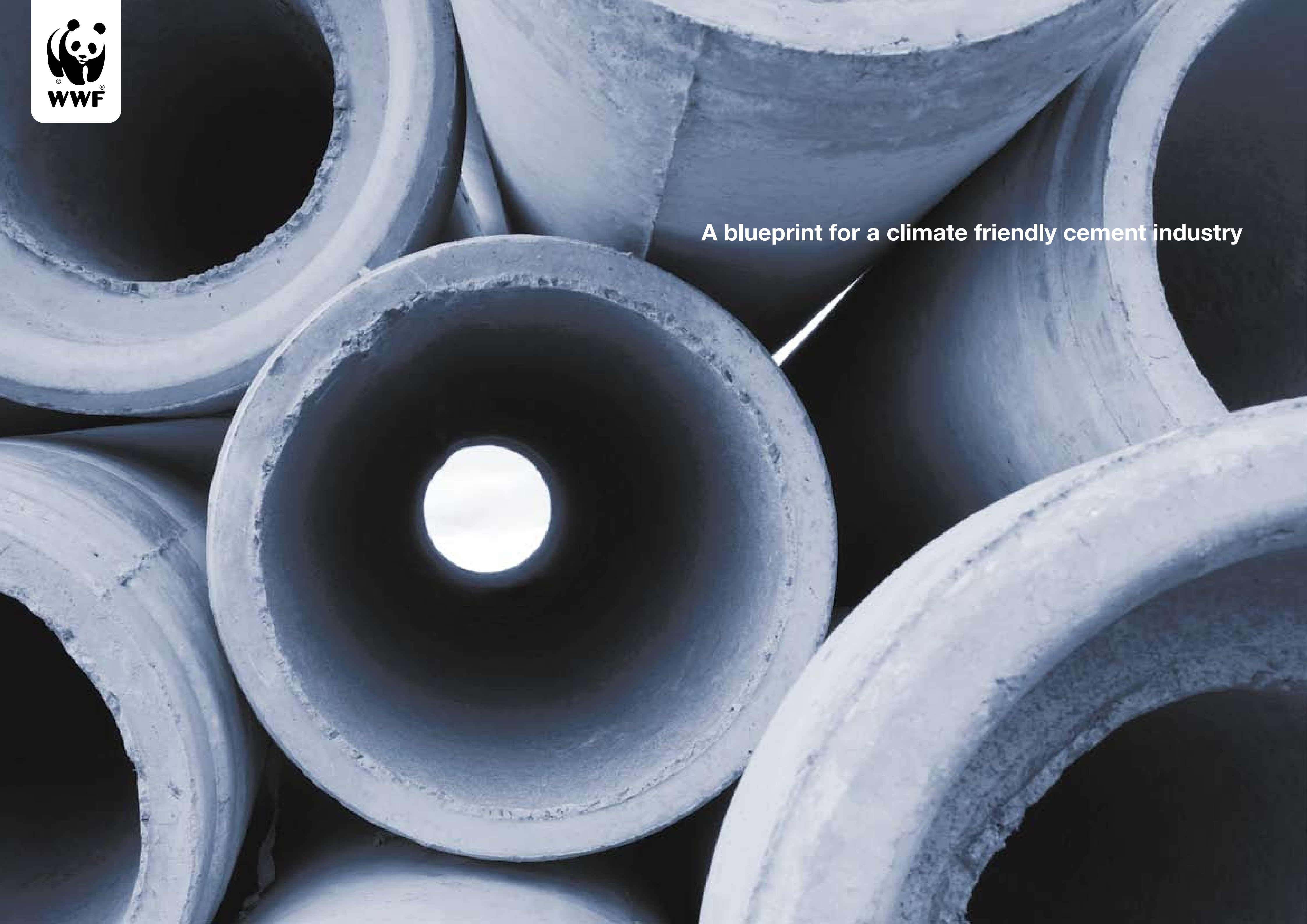
A blueprint for a climate friendly cement industry



How to Turn Around the Trend of Cement Related Emissions in the Developing World.

A report prepared for the WWF –
Lafarge Conservation Partnership

On behalf of:
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The crisis of climate change needs urgent solutions. This report proposes solutions for an industry sector which is responsible for 8% of global CO_2 emissions, the cement industry.

As economies grow and get wealthier, the demand for construction materials such as cement and concrete is booming. This is particularly visible in emerging economies. The global cement industry is facing the challenge to sustain its business while decreasing its carbon intensity, from production processes, fuel uses and its product end use.

Science tells us that the world must reduce its emissions of greenhouse gases by at least 80 per cent below 1990 levels by 2050. WWF insists that developed countries show the way to this goal with decisive actions to reduce their emissions by 25-40 per cent below 1990 levels by 2020 while supporting and financing additional emissions reductions in carbon- and energy-intensive sectors in developing nations.

This report offers a range of solutions to enable cement companies to turn around their growth of CO_2 emissions and shows how the cement industry can contribute to the task ahead of us. It describes a scenario in which the industry sector grows to more than twice its size in volume by 2050 while it reduces its absolute CO_2 emissions by approximately three quarters compared to global emissions in 2007. Compared to a business-as-usual scenario, the reduction options are even more impressive: the avoided CO_2 emissions amount to 90% compared to the situation in a “frozen technology scenario” in 2050.

WWF believes that cement companies around the world must take steps to reduce their carbon footprint today, both in emerging economies and industrialized countries. The solutions proposed in this report can help the industry move in the right direction, set targets and take action that will lead to deep greenhouse gas emission reductions.

It is clear that these actions need support from a corresponding policy framework, which must be based on strong caps on overall emissions in developed countries. At the same time, the framework must ensure that developing countries, in particular emerging economies, deviate substantially from a business-as-usual development path.

To make this possible, sufficient financial resources and technology must be made available from developed countries. A policy framework specifically for the cement sector must contain the following elements:

- Policy regulations taking effect as soon as possible, which guarantee that any newly built or retrofitted cement plants install only best available technology.
- A technology action programme to enable the industry to reach globally set sectoral standards. This action programme should receive financial support for Non-Annex 1 countries from Annex 1 countries.
- Policies to support cross-sectoral mitigation efforts, as the end-user industries such as the construction industry will play a crucial role in the efficient and appropriate use of cement. This type of cross-sectoral mitigation effort has been largely unexplored to date.
- Policies that guarantee the sustainable production of biomass energy sources, which could reduce the industry's dependency on fossil fuels.
- Standardized criteria and screens for financial service companies to define and integrate the climate risk of the cement sector and individual cement companies.

While this report in particular focuses on solutions for the cement sector in China, it is obvious that these solutions can and must be transferred to other countries as well, including industrialized countries. The carbon intensity of cement production in industrialized regions, in particular in North America, is sometimes worse than that in emerging economies. WWF urges cement producers all around the world to develop serious action and investment plans to achieve a low carbon business model for their industry.

WWF would like to thank the authors from Ecofys, as well as the experts and reviewers in China and elsewhere for the excellent work contributed to this report. WWF would also like to thank Lafarge staff in France and China for contributing their expertise and time to this report.

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We would like to thank the following persons for their input made during and after the study trip to China:

Sui Tongbo Vice President, Chinese Building Materials Academy.

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Zhang Ruiying Program Officer, China Sustainable Energy Program, Energy Foundation.

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Frederic Vallat Resource Recovery Manager, Lafarge.

Liu Zuoyi Senior Consultant, DigitalCement.

Further we would like to thank all reviewers who contributed to this report through their comments: Lynn Price (Lawrence National Berkeley Laboratories), Prof. Niklaus Kohler (University of Karlsruhe), Prof. Elmar Bollin (University of Applied Sciences Offenburg), Wang Lan (China Building Material Academy) and Ying Chen (Chinese Academy of Social Sciences).

This report was prepared as a master thesis by Nicolas Müller at the University of Applied Sciences Offenburg (Germany) under the supervision of Prof. Elmar Bollin (University of Applied Sciences Offenburg) and Dr. Jochen Harnisch (Ecofys Germany GmbH in Nürnberg (Germany)).

The complete report can be downloaded at www.panda.org/climatesavers

1. Executive Summary

The continued growth of key world economies results in an increasing demand for construction materials. As a consequence, the global production of cement in 2030 is projected to grow to a level roughly five times higher than its level in 1990, with close to 5 billion tonnes worldwide [1]. This has a significant impact on the overall level of anthropogenic greenhouse gas (GHG) emissions as the production of each tonne of cement leads to emissions of roughly 0.89 tonnes of carbon dioxide [2]. As a consequence, the emissions of the global cement sector alone are very likely to surpass the total amount of CO_2 emissions of the EU before 2030. This report attempts to identify the drivers of this process and explore options to mitigate emissions.

1.1 Rapid expansion of production in developing countries

Figure 1.a shows the rapid expansion of global cement production since 1990, which mainly stems from production increases in China. The viewgraph also shows projected future increases of cement production. Many new cement plants are going to be built in the next decade, especially in developing countries. Their lifespan will probably exceed 40 years. In a future carbon constrained world, the profitability of individual plants will depend on their CO_2 intensity. Significant emissions reductions at existing plants by improving the technology and operating practices are achievable. The accelerated closure of outdated plants with low efficiency can also make substantial contributions to emission reductions.

1.2 Cement related emissions and future climate action

Globally, widespread agreement has been reached that the threat of climate change is real. Global action needs to be taken to reverse the increasing trend of global greenhouse gas emissions. During the next 10 years, global emissions levels should be reduced to 50% less than their 1990 levels by 2050. This will reflect the so-called 450 ppm stabilization scenario aiming to limit global warming during the 21st century to 2°C [3]. These objectives find growing acceptance, including at the international policy level. They are likely to be implemented in negotiations under the umbrella of the United Nations.

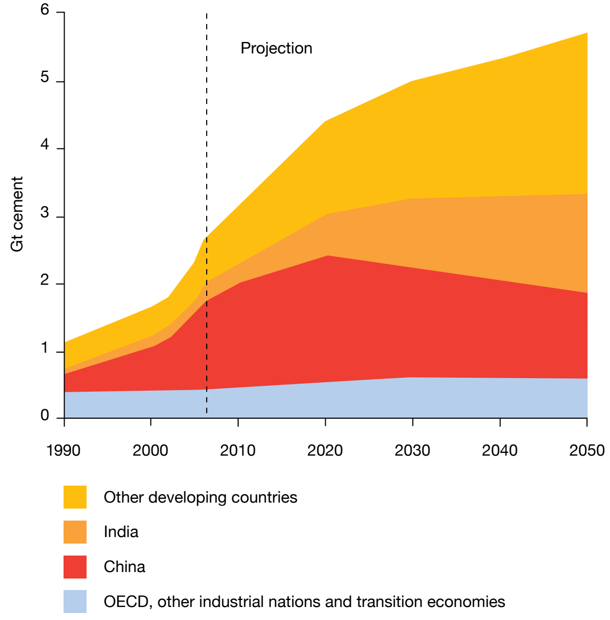
By 2006, cement production contributed to roughly 8% of worldwide anthropogenic CO_2 emissions [4] or 6% of total anthropogenic greenhouse gas emissions. Despite significant improvements in efficiency, cement related emissions are expected to increase by 260% throughout the 1990-2050 period (Figure 1.b).

As a result, the challenge arises of how to transform the traditional way of producing cement into a sustainable business model, and how efforts to reduce the emissions from the cement sector can be implemented in a timely fashion.

1.3 Conventional and advanced emission reduction options

Currently the production of one ton of cement commonly results in the release of 0.65 to 0.95 tonnes of CO_2 depending on the efficiency of the process, the fuels used, and the specific type of cement product. Considering the scale of, the worldwide cement production, even a slight decrease in the average global emissions per ton has a large CO_2 reduction potential. Every 10% decrease in the cement CO_2 intensity by 2050 could save around 0.4 Gt CO_2 [5], and substantially contribute to slowing climate change.

Figure 1.a
Cement production in industrialized and developing countries [1]



Typically, around 55% of the CO_2 emissions in the production of cement clinker originate from the conversion of limestone ($CaCO_3$) into lime (CaO). Around 40% of the emissions result from combustion processes needed to yield the thermal energy required for this reaction (1450°C). Through energy efficiency measures, emissions and fuel costs can both be considerably reduced. The use of biomass as substitutes to carbon intensive fuels can contribute substantially to reducing emissions of fossil CO_2. By reducing the electricity consumption of one plant additional emissions reductions are possible which could contribute up to 10% of total emissions, depending on the local electricity mix.

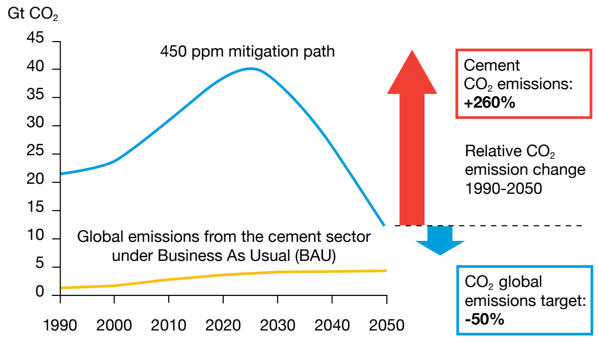
Further abatement could originate from the more efficient use of cement and concrete. Even large cement producers cannot significantly influence the demand for building materials. However they can guide participants in the building sector in their specific choices, especially in cooperation with governments. Similar to energy efficiency, or avoided energy consumption, the avoided or reduced consumption of concrete deserves full consideration.

When used in a more efficient way, high strength, specialty concrete or even ordinary concrete and cement products can largely decrease the overall quantity of material used to meet the requirements for projects. The extension of specified lifetimes of buildings from only a few decades to at least a century is also a potent long-term reduction measure of cement demand and related emissions.

Additionally, innovative low CO_2 cementitious materials are to be considered as a reduction measure. The potential CO_2 reduction using different kinds of advanced products and optimizations is significant. In the light of the required emission mitigation pathways, they have to obtain large market shares before 2050. These products also require the distribution of information and know-how on all levels and will require the changes to relevant building codes and standards.

The following section provides an overview of the key types of technical measures available to achieve significant reductions of greenhouse gas emissions.

Figure 1.b
Cement emission forecast vs. mitigation path



Cement Production

1.3.1 Improve the thermal efficiency of kilns

The most efficient solution regarding the production of clinker in new kilns, (new rotary kilns with pre-calciner and suspension pre-heaters), is widely applied already today, including in China. It is important to ensure that all new plants are built according to the best available technology. The equipment in numerous plants worldwide is still very far from the best being able to achieve efficiency; energy consumption can reach twice the level of the best available technology and practices. The efficiency of some of these plants can greatly be enhanced through upgrades. Outdated technologies should be phased out because of low efficiency as such plants are commonly heavy polluters and the quality of the cement produced is often inferior. This inhibits the switch to good practices and high quality products.

1.3.2 Increase the share of biomass

The use of biomass in cement kilns is still quite low in the developing world, even if close to 40% were achieved in Brazil. Despite favorable tropical weather which allows a fast growth of the biomass its share as kiln fuel is under 5% in most developing countries. Setting a long term goal of 40% of sustainable biomass in the fuel by 2050 is challenging but achievable. It would require a long term sustainable supply chain for biomass fuels originating from forestry, biological wastes or crops.

1.3.3 Improve the electrical efficiency of plants

Large improvements can be achieved regarding electricity consumption and efficiency. Less than 40 kWh are consumed per ton of cement using WHR (Waste Heat Recovery) and very efficient equipment. This corresponds to a reduction of the current plant electricity consumption by two thirds. This is especially important in countries with a carbon intensive electricity mix. A maximum consumption of electricity in kWh / ton of cement can be agreed between cement companies with developing countries governments for all new plants with WHR (Waste Heat Recovery) as a requirement. At the same time, a goal could be applied for existing plants with increasing targets. This could be done in the frame of a voluntary agreement with all cement companies.

1.3.4 Develop Carbon Capture and Storage (CCS)

Reducing the CO_2 generated from the cement sector on a scale and in a timeframe compatible with the mitigation scenario is difficult. The sequestration of the CO_2 produced can be a solution for a low-carbon future. This technology could cover a majority of the cement emissions by 2050. Only 3,000 cement plants worldwide could supply the 5 Gt cement demand by 2050. In order to be able to recover the CO_2 from all plants by then, it is important that new plants are designed in a way that would allow an upgrade with CCS. Plants which use biomass and are equipped with CCS would remove carbon from the atmospheric cycle and as such have the potential to reduce the CO_2 in the atmosphere.

Use of Cement

1.3.5 Use cement more efficiently

Focus can first be set on specifically answering the required function of a project rather than simply delivering a certain quantity of material. In several cases, the concrete consumption can be reduced, sometimes by more than 50%, by applying the right design, and switching to high quality or special concretes. This requires an enhanced cooperation with the customer as well as improved education, information and training on the most advanced alternatives available from cement suppliers. It also requires sound scientific methods and quality controls to be applied throughout the whole life-cycle of cement from production to use.

1.3.6 Expand the use of additives and substitutes to cement clinker

The use of Ordinary Portland Cement is the established business practice in the building sectors of most industrialized and developing countries. Conventional and advanced alternatives to Portland cement can lead to substantial CO_2 reductions ranging from 20 to 80% depending on the case.

Until now, the use of additives and substitutes to Ordinary Portland Cement (OPC) clinker has been one of the most successful measures in decreasing the specific CO_2 emissions from making cements. A long term clinker ratio as low as 0.75 is desirable. Such a target is still challenging since the availability of additives will not necessarily grow at the same rate as the cement demand.

If new alternatives to Portland Cement can account for 20% of the market by 2030, they would lead to a 10% decrease in CO_2 emissions from the sector. The introduction of new alternatives to Portland cement is generally very challenging and is expected to take a long time. Therefore, it is advisable to start this process as soon as possible, especially in countries which are still in an earlier stage of development. For this purpose, pilot projects and applications could be developed to "lead by example". Large projects use large quantities of cement for one single customer. Such projects are ideally suited for the introduction of new alternatives to Portland cement before having the technology spread to a broader customer basis. Strong carbon financing or other incentive tools could greatly help to launch these substitutes until they start to spread on their own.

1.4 The result: a pathway to a low carbon cement industry

Most options can be implemented independently. Table 1.a gives an overview of the discussed technical options and shows respective reduction potentials.

Table 1.a
Potential greenhouse mitigation measures and respective potentials until 2050 based on a reference "frozen technology" scenario assuming a consumption of 5.7 Gt cement of cement in 2050 with a constant CO_2 intensity of 0.89 t CO_2 / t cement through 2005-2050 leading to 5.1 Gt CO_2 emitted in 2050 from the cement production

Measures	Quantification (all figures are given on a per year basis)
Use cement more efficiently; especially cement used for buildings. Reduce the need for concrete and switch to higher qualities with higher added value. Eliminate low quality concrete for applications. *Set a goal for an efficient cement use which would lead to an equivalent of a 15% decrease of cement related CO_2 emissions by 2050*	15% consumption avoided = 0.86 Gt cement avoided = 0.75 Gt CO_2 avoided Remaining quantity of cement to be produced = 4.84 Gt Remaining CO_2 emissions = 4.32 Gt
Further expand the use of additives and substitutes to produce blended cements and promote alternatives to Portland Cement on large projects to "lead by example" and increase their share in the market.	*Decrease the clinker ratio to 0.75 worldwide by 2050 (from 0.87 in 2005)* 0.88 Gt CO_2 avoided Remaining quantity of clinker to be produced = 3.09 Gt Remaining CO_2 emissions from the clinker production = 3.12 Gt
Improve the thermal efficiency of kilns: to encourage and develop CO_2 reductions using the best available technology combined with good practices *Improve the average kiln efficiency from 4.4 GJ / t clinker in 2005 to 3.0 GJ / t in 2050*	Energy saved in the kiln = 0.375 Gt CO_2 avoided Use of 9.27 EJ instead of 13.60 EJ Energy need reduced by 4.33 EJ
Improve the electrical efficiency of plants on new and existing cement plants through WHR (Waste Heat Recovery) and efficient equipments. *Reduce the net electrical consumption of all cement plants to 40 kWh / t clinker by 2050*	Emission savings: = 0.125 Gt CO_2 avoided (based on the displacement of coal)

Measures	Quantification (all figures are given on a per year basis)
Increase the share of biomass in the fuel mix Set a long term goal of 45% of sustainable biomass fuel by 2050 in the fuel mix for cement kilns	The equivalent CO_2 saved from the displacement of coal as a fossil fuel is around 0.41 Gt
Resulting CO_2 emissions per year	**Fossil origin: 2.12 Gt**
(G) Develop Carbon Capture and Storage (CCS) with the target to reach a high sequestration of CO_2 emissions by 2050. Develop now plants which are able to be upgraded with CCS. *Reach a 60% CO_2 sequestration share by 2050.*	60% of the real CO_2 stream sequestrated = 1.54 t CO_2 captured per year Remaining NET CO_2 emissions of CO_2 in the atmosphere by 2050: **0.6 Gt / year**

From combining these measures, the resulting Global Mitigation Path has been quantified and compared to a "frozen technology scenario" in which the CO_2 intensity would remain at the level of 2005 by 2050. Figure 1.c visualizes the quantitative impact of each "reduction wedge" against the reference trend of emissions.

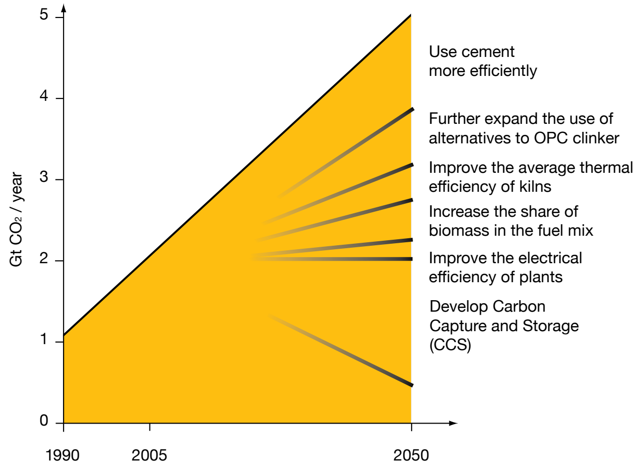
1.5 Making it happen – a climate-friendly cement industry

In order to rapidly progress towards a low-carbon cement sector in developing and developed countries, a combination of different measures have to be taken in order to implement the technical options. The following list provides a portfolio of options. A summary overview is given in Table 1.b at the end of this list.

(1) Implement a global sectoral approach for the cement industry

Policy or market instruments guaranteeing a certain minimum efficiency of cement plants can be applied by a country, a region or on an international basis in order to have a rapid convergence worldwide towards the best achievable technology and efficiency. Both countries and companies have the possibility to set a minimum standard of efficiency for all new cement plants. Such an approach of a minimum standard in the sector could also be integrated into future climate agreements. Moreover, carbon credits could provide an incentive for plants to achieve a higher performance, based on enhanced technologies and application of best practices.

Figure 1.c
Impact of different reduction levers on cement related emissions in 2050



Specific tools to accelerate the phase-out of bad practices and outdated technologies are currently missing in the international framework. Financial incentives for the closure of outdated plants are especially lacking. New approaches to retire a maximum of outdated plants can be established in the framework of the Kyoto Protocol (and its successor) with an agreed target to progressively retire plants according to their fuel consumption. In order to accelerate the movement, governments could reduce taxes on imports for advanced technologies or introduce penalty taxes on cement plants with poor efficiency.

(2) Make CO_2 reductions integral part of the business model

Together with building academies, civil engineering companies and environmental groups, leading cement companies should become leaders in low CO_2 construction. Cement companies have the possibility to start strengthening their skills on the CO_2 consulting field now to provide customers with solutions which have the lowest impact on the climate.

Cement companies, together with building associations and academies should promote the switch to high strength and low CO_2 materials. By switching to high quality cement with a high added value, the companies can enhance their profitability while reducing the quantities and still be answering the demand for construction materials as sufficiently as they do today. In many countries, first steps have been taken to progressively reduce the share of low strength cement produced. A gradual ban of the lowest qualities can be envisioned through the implementation of minimum standards for different applications. The increased use of innovative building materials can play an important role in emissions reduction strategies.

Generally, such new kinds of reduction programs could be implemented under the “Programmatic Clean Development Mechanism” which rewards the result of a program or policy rather than the result of a single project. The development, spread and use of this instrument is essential and could also be part of a future post-Kyoto treaty. Generally, strong measures could accelerate the market penetration of alternative cementitious materials like fiber re-inforced concretes or belite cements up to a critical scale. As such, a policy rewarded by carbon credits is a good instrument to promote these materials.

(3) Improve the framework for the use of substitution materials

Substitution materials used as binder and mixed with cement already avoid large amounts of CO_2 emissions. Their use can be increased to 35% locally in the cement mix. Several developing countries are going to build a large number of coal power plants in the coming decades. Producing high quality ashes with low carbon content is essential. Used in blended cement, the substitution material provides the same decrease in the CO_2 emissions as increasing the efficiency of a power plant. In turn, standards can be set for the quality of ashes, possibly using tax and discount instruments. Furthermore, the potential positive impact of ashes on the power plant energy balance and economics should be assessed. For this purpose, operators and technology suppliers of coal power plants need to be involved from an early stage.

(4) Set up goals for a growing share of biomass

Cement companies should set up a long term sustainability goal for the use of biomass. Together with national governments and environmental groups, cement companies can develop a program for the sustainable use of biomass resources. This could lead to a 2050 goal of 50% average use of biomass in the fuel mix worldwide, which is very close to the current technological limit. However, an increase in biomass use must go hand in hand with the assurance of sustainable biomass sources.

(5) Update standards for cements

In order to obtain a large share of the market, blended cements or even advanced alternative cementitious materials require product standards in order to permit a judgment based on their performance (e.g. strength, setting time, CO_2 per ton), not on their chemical composition which might be different from ordinary Portland cement. This process should involve cement companies, cement associations as well as individual governments and national and international standardization bodies.

(6) Create new international policy instruments for the construction sector

All parts of the whole life cycle chain of cement, concrete and final products or construction projects should be taken into consideration for CO_2 reductions. This requires the development of proper instruments related to programs, national policies or carbon markets. Ideally, a large number of these options could be identified, quantified and verified to qualify as emissions reductions and be rewarded by national policies or carbon markets.

One way to proceed could be to integrate the CO_2 factor in the bidding for large projects. Additionally, a policy could be set up to lower the quantity of CO_2 used per building surface built.

Discussions on the international level should consider these aspects for their integration into a Post-Kyoto agreement.

(7) Establish market based instruments on the national level

Financial instruments could be set up easily to target the fossil fuel consumption of the cement industry. A global “cap and trade” system where the emission permits for the cement sector are limited would deliver financial incentives to decrease the carbon intensity. Such a “cap and trade” system can be implemented in various forms [6].

Putting a carbon price on fuel use or emissions creates an incentive for the most efficient plants to fully use their capacity and at the same time restrains the use of the most inefficient ones. Consequently, this would create a large incentive to recover and use as much biomass fuels. If set up properly, the instruments would encourage new plants to be built using even more efficient technologies, and accelerate the phase out of the least efficient.

(8) Extend research for advanced technologies

Compared to other CO_2 emitting sectors, the current research activities on CO_2 emission reduction options for the cement sector are relatively small considering that the sector is likely to account for more than 10% of total global GHG-emissions in the period 2030-2050. Networks in the research towards a long term low-CO_2 cement industry need to be strengthened by means of cooperation between companies, universities and governments with special clusters in specific countries.

The following points have been identified in this report as especially relevant to the cement sector:

- In a long term future for cement alternatives requiring lower kiln temperatures (700-800°C), explore the possibility of using solar via concentrators as a source of energy.
- Research advanced cogenerations such as integrated cement and power plants.
- Explore the possibility of CCS (Carbon Capture and Storage) to sequestrate CO_2 exhaust gases and avoid releasing them into the atmosphere. Using waste heat through absorption chillers to prepare oxygen for oxygen arc furnaces is a possibility which would increase the thermal efficiency. The resulting CO_2, which is nearly pure, could be sequestrated and other Greenhouse Gases like NOx reduced to nearly zero.

(9) Intensify international capacity building

On multiple levels, an essential element for emissions reductions in the cement sector in developing countries is capacity building. The transfer of skills, competences and knowledge etc. regarding processes and products is required to efficiently put these CO_2 abatement measures into practice. This calls for strong capacity building activities. However, those that have this specific knowledge, which provides a competitive advantage over other cement companies, can be expected to resist these processes or to request a fair compensation.

A key part of the capacity building would be to spread the knowledge on emission reduction options and supporting instruments on a regional level. This can be achieved through education and by employing dedicated specialists for waste, biomass recovery and energetic efficiency at existing plants. Best practices can be spread on a plant level.

The introduction of innovative cementitious material strongly needs capacity building to surpass barriers on multiple levels. The capacity building activities should also address the legal framework at national or larger level in order to achieve widespread emission reduction. New standards for cement could ease the use of blended and alternative cements. Minimum efficiency standards for plants can be set and financial instruments can be used.

Table 1.b
Potential: policies and measures to reach the emissions goals

Potential action	Stakeholders	Timeframe
(1) **Implement a global sectoral approach for the cement industry**	Cement companies / NGOs Countries UNFCC	Short and medium term
(2) **Expand the scope of CO_2 reductions** by starting to integrate a CO_2 reduction consulting service in the companies	Cement companies NGOs	Short term
(3) **Improve the framework for the use and the availability of substitution material**	Cement companies Industrial producers of substitution material	Medium term
(4) **Set up a goal for a growing share of biomass** On the basis of internal goals and / or on a voluntary agreement for specific regions of the world.	Cement companies Developing countries NGOs	Medium and long term
(5) **Update standards for** cements to allow a maximum blending of cements with clinker substitutes in all countries and allow alternative cementitious materials	Cement associations Cement companies Countries	Short and medium term
(6) **Create new international policy instruments on the construction sector** in order to promote a low CO_2 path of the construction sector	Cement companies Producers of substitute an additives for cement National governments	Long term goal
(7) **Establish market based instruments on the national level** such as fuel taxes or a cap and trade system.	Countries Cement companies	Medium and short term
(8) **Extend research for advanced technologies** for long term CO_2 decrease: Solar concentrators, Oxygen arc-furnace with CCS, solar air preheater, advanced cogenerations	Cement companies Governments Research institutes	Long term
(9) **Intensify international capacity building** **Spread the knowledge about possible reduction CO_2 opportunities** across the cement, concrete and building materials chain, including on a local level (producers, users, etc.). **Provide advisory capacity on improvements on the legal frame.**	International institutions Developing countries Annex 1 countries Major cement companies	Short and medium term

1 Own estimates based on figures from:

The European Cement Association. (May 2006). *Activity report 2006*, retrieved from the Cembureau website http://www.cembureau.be/Documents/Publications/Activity%20Report%202006.pdf

US Geological Survey. (January 2007). *Mineral Commodity Summaries*, retrieved from the USGS website http://minerals.usgs.gov/minerals/pubs/commodity/cement/cemenmcs07.pdf

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2 The European Cement Association. (2000-2007). Retrieved May 2006 the Cembureau website, *Keyfacts* http://www.cembureau.be/Key_01.asp

3 WRE 450 Emission Scenario from:

UNEP International Panel on Climate Change. (2001). *Emissions, concentrations and temperature changes corresponding to different stabilization levels for CO_2 concentrations* http://www.ipcc.ch/present/graphics/2001syr/large/02.18.jpg

4 Percentage based on the global CO_2 emissions and the cement sector CO_2 emissions:

Own calculation for the CO_2 emissions from the cement industry corrected for 2006 based on:

Vattenfall AB (June 2006) *Global Mapping of Industry Greenhouse Gas Abatement Opportunities up to 2030: Industry Sector Deep-dive* retrieved on http://www.vattenfall.com/www/ccc/ccc/Gemeinsame_Inhalte/DOCUMENT/567263vattenfall/P0272863.pdf

Lynn Price, Ernest Orlando Lawrence Berkeley National Laboratory & Ernst Worrell, Ecofys. (4-5 September 2006). *Global Energy Use, CO_2 Emissions and the Potential for Reduction in the Cement Industry* internal Ecofys-LBNL source

Global CO_2 emissions from:

Netherlands Environmental Assessment Agency MNP, using BP energy data. (BP, 2007). *Global CO_2 emissions* retrieved from the MNP website at:

http://www.mnp.nl/mnc/c-0533-001g-mnc-02-nl-xls.html and http://www.mnp.nl/en/dossiers/Climatechange/moreinfo/Chinanowno1inCO2emissionsUSAinsecondposition.html

5 Own estimates based on the own corrected IEA prognosis from Michael Taylor (2006)

6 Jane Ellis, OECD and Richard Baron, IEA (17 nov 2005) *Sectoral Crediting Mechanisms: An Initial Assessment of Electricity and Aluminium*, JT00194332

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