Technology Roadmap

Low-Carbon Technology for the Indian Cement Industry

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Foreword

Current trends in energy supply and use are unsustainable – economically, environmentally and socially. Without decisive action, energy-related emissions of carbon dioxide (CO_2) will more than double by 2050 and increased fuel demand will heighten concerns over the security of supplies. We can and must change our current path, but this will take an energy revolution and low-carbon energy technologies will have a crucial role to play. We must also ensure that investment decisions taken in the near term do not saddle us with sub-optimal technologies in the long term. Every major country and sector of the economy must be involved.

Awareness is growing of the urgent need to turn political statements and analytical work into concrete action. To spark this movement, the International Energy Agency (IEA) is leading the development of a series of roadmaps for key industries and some of the most important technologies. By identifying the steps needed to implement radical technology changes, these roadmaps will enable governments, industries and financial partners to make the right choices. This will in turn help countries and societies make the right decisions.

Since 2002, cement-producing companies in the Cement Sustainability Initiative (CSI), a project of the World Business Council for Sustainable Development (WBCSD), 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. In 2009, recognising the urgency of identifying technology to reduce the energy use and CO_2 intensity of cement production, CSI member companies around the world (representing about 30% of global cement production) worked with the IEA to develop the first industry roadmap. That roadmap outlines emissions reduction potential from all technologies that can be implemented in the cement industry.

Building on the success of the global roadmap, IEA and CSI, in collaboration with the Confederation of Indian Industry (CII) and the National Council for Cement and Building Materials (NCB), joined together to develop a roadmap specifically for the Indian cement industry. This initiative was supported and part-funded by the International Finance Corporation (IFC).

In 2010, the Indian cement industry's share of the country's total energy and process CO_2 emissions was around 7%. Taking into account the specificities of the Indian context, markets and opportunities, this roadmap outlines a possible transition path for the Indian cement industry to support the global goal of halving CO_2 emissions by 2050. The roadmap estimates that the Indian cement industry would reduce its direct CO_2 emissions intensity to 0.35 tonnes (t) of CO_2/t cement in 2050, about 45% lower than current levels, a saving of between 212 million tonnes of CO_2 ($MtCO_2$) and 367 $MtCO_2$ compared to a business-as-usual scenario. This is nearly as much as the 2009 total energy-related emissions of Thailand (228 $MtCO_2$) or Indonesia (376 $MtCO_2$). Despite this improvement in CO_2 intensity, the total emissions, however, would rise from the current 137 $MtCO_2$ to between 275 $MtCO_2$ and 468 $MtCO_2$ in 2050 due to rapid growth in cement demand, in line with economic growth in India.

The vision is realistic; the targeted reductions ambitious. The changes required must be practical, realistic and achievable. This roadmap is a first step. It is attainable only 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 making recommendations to support research and development and future decision making for investment.

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Acknowledgements

This publication was prepared jointly by the International Energy Agency (IEA) Directorate of Sustainable Energy Policy and Technology and the World Business Council for Sustainable Development's Cement Sustainability Initiative (WBCSD CSI). It was developed under the lead of Caroline Twigg (WBCSD CSI) and Nathalie Trudeau (IEA). Cecilia Tam and Dagmar Graczyk from the IEA provided significant input and support throughout the development of this roadmap.

The Confederation of Indian Industry (CII) provided essential input to the development of this roadmap, including co-authoring the technical papers that fed into it and overseeing stakeholder outreach, led by Kiran Ananth. AK Mishra, SK Chaturvedi and SN Pati of the National Council for Cement and Building Materials (NCB) co-authored the technical papers. The scope of this project has been expanded thanks to financial support from the International Finance Corporation (IFC). Thanks go to this organisation for its support, in particular Sivaram Krishnamoorthy.

This work was guided by the IEA Committee on Energy Research and Technology. Bo Diczfalusy, Director of the Directorate of Sustainable Energy Policy and Technology, Jean-François Gagné, Head of the Energy Technology Policy Division and Lew Fulton, former Head of the Energy Technology Policy Division, provided guidance and input.

Special thanks go to:

- **The Expert Working Group Co-Chairs in India (ACC Ltd., Shree Cement, UltraTech Cement Ltd.)**: SJ Herwadkar, KN Rao and Daniel Raju for their input and guidance throughout the project;
- **The full Expert Working Group**: Rakesh Bhargava, Jagdish Dhumale, Dominic Fernandes, R. Gopi, Ashish Gupta, Sanjay Jain, SA Khadilkar, Sajid Khan, Jitander Kumar, UV Parlikar, L. Rajasekar, Sandeep Shrivastava, R. Vasudevan and PS Raju; and
- **CSI members of the global Task Force Climate Protection**: Rob van der Meer, Bruno Vanderborght, Manuela Ojan and Volker Hoenig.

Thanks go to NA Viswanathan and SK Handoo from the Cement Manufacturers Association (CMA) India for engagement in the roadmap development process.

The authors would also like to thank the IEA publication unit, especially Muriel Custodio, Astrid Dumond, Rebecca Gaghen, Cheryl Haines, Bertrand Sadin and Marilyn Smith for their assistance, in particular on editing, layout and design.

Finally, the authors would like to thank the industry, government and non-government experts who attended meetings, reviewed and commented on drafts, and provided feedback and guidance. The complete list of participants and reviewers is available from IEA and WBCSD websites (www.iea.org/roadmaps and www.wbcsdcement.org/india-tech-roadmap).

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Key findings

The Indian cement industry is one of the most efficient in the world, yet, because the manufacturing process relies on the burning of limestone (calcium carbonate), it still produces 137 million tonnes (Mt) of carbon dioxide (CO_2) in 2010 – approximately 7% of India's total man-made CO_2 emissions.

- The Indian cement industry has made strong efforts to reduce its carbon footprint by adopting the best available technologies (BAT) and environmental practices. Through this, it has successfully reduced total CO_2 emissions to an industrial average of 0.719 tonnes (t) of CO_2/t cement in 2010 from a substantially higher level of 1.12 tCO_2/t cement in 1996.
- In the absence of policy actions or technology development,[1] *i.e.* in a business-as-usual scenario, CO_2 emissions from the Indian cement industry are projected to reach between 488 $MtCO_2$ and 835 $MtCO_2$ by 2050. This represents a 255% to 510% increase compared to current emissions.
- The technologies, policy frameworks and investment needs outlined in this roadmap could reduce CO_2 intensity in the Indian cement industry by about 45% by 2050, from the 2010 level. This would limit CO_2 emissions growth to between 100% (Low-Demand Case) and 240% (High-Demand Case) compared to the current level.
- The milestones for the Indian cement industry set out in this roadmap would enhance energy security by saving between 377 petajoules (PJ) and 485 PJ of energy in 2050 compared to a business-as-usual scenario.
- Key levers to reduce emissions in the Indian cement industry are increased rates of blending leading to a reduction in clinker-to-cement ratio, increased use of alternative fuels, widespread implementation of waste heat recovery (WHR) systems, and a radical step change in new technology development to bring potential technologies from research and development (R&D) to deployment. As energy efficiency in the Indian cement industry is already high, there is limited scope for improvement in this area, providing continued use of energy efficient technologies in new plants.
- Captive power plants (CPPs) offer important energy security enhancement and emissions reduction opportunity. Assuming that CPP will continue to account for 60% of the cement electricity needs in 2050, as much as 80 $MtCO_2$ to 150 $MtCO_2$ could be saved through efficiency improvement and use of alternative energy sources.
- The additional investment required in the Indian cement industry (based on net present value) to achieve the CO_2 emissions reduction set out in this roadmap is between USD 29 billion and USD 50 billion (INR 145 000 crore[2] and INR 250 000 crore), or 15% to 25% higher than in a business-as-usual scenario.
- To ensure widespread deployment and implementation of such technologies in the future, social acceptance, political will and policy development, and financing mechanisms, must be supportive.

1. See Box 1 page 6 for more information on the different scenarios used in this roadmap.

2. In this roadmap, INR denotes the Indian rupee and USD the United States dollar; an exchange rate of USD 1 = INR 50 has been used. INR 1 crore = INR 10 000 000 (USD 200 000).

Key actions in the next ten years

Decisive action by all stakeholders is critical to realise the vision laid out in this roadmap (see Roadmap action plan on page 40). To achieve the envisioned levels of efficiency improvements and emissions reduction, government and industry must take collaborative action. An investment climate that will stimulate the scale of financing required must be created. In particular:

- All stakeholders in India should intensify national and international collaboration to drive implementation of BAT and existing know-how, and to share experience and knowledge. The Indian cement industry should deploy existing state-of-the-art technologies in new cement plants and retrofit existing plants with energy efficient equipment when commercially viable.
- At the cement plant level across the country, assessments should be performed to analyse how low-carbon technologies can be implemented, and action plans developed to increase the speed and scale of implementation. CSI member companies in India have started this targeted work as an immediate follow-up from the India roadmap project.[3]
- The Government of India needs to ensure strong regulations and standards are in place to enable increased use of clinker substitutes, and should support allocation of good quality linkage coal to the cement industry so low-grade limestone reserves can be used and the cement industry can consume surplus fly ash from coal-based power generation units. Waste legislation is also required to support the use of alternative fuels and raw materials (AFR) in cement kilns. Emissions monitoring must be regulated.

3. Please refer to Box 2 page 7 for more information on this project.

- Public and market barriers that currently impede co-processing[4] (*e.g.* for hazardous waste) and AFR use in India must be addressed through modified regulation, awareness-raising campaigns and industry training. Awareness-raising and education is also required to ensure acceptance of blended cement by the Indian market and widespread dissemination.
- Expand public awareness campaigns, international collaboration and financing for demonstration of carbon capture and carbon use at cement plants. Develop near-term approaches to facilitate carbon capture and use demonstration.
- Globally, elaborate approaches to facilitate carbon capture and storage (CCS) demonstration and establish the technical and commercial viability of CCS.
- For new and alternative technologies, such as nanotechnology and geopolymer cement, government to ensure sustained funding and support mechanisms are in place nationally and internationally to support their development and deployment to offer potential for CO_2 emissions reduction. Provide a major thrust in R&D to move through pilot to demonstration phases to widespread deployment. For existing technologies, Government of India must develop policy and fiscal incentives. Regulatory frameworks must also support greater financial viability of WHR power generation, including providing WHR with renewable energy status and providing associated incentives.

4. Co-processing is the use of suitable waste materials form municipal areas or other industries in manufacturing processes, as a substitute for primary fuel or for raw materials.

Introduction

Objective of the roadmap

The collaboration to develop the *Technology Roadmap: Low-Carbon Technology for the Indian Cement Industry* stemmed from the previous joint effort, by the IEA and WBCSD, to publish a global strategy entitled *Cement Technology Roadmap 2009* (IEA/WBCSD, 2009).[5] The global roadmap outlines four key levers, and policy and financial support necessary, to reduce CO_2 emissions within the cement manufacturing process. Understanding the potential of such a roadmap to identify and trigger emissions reduction up to 2050, the members of the CSI in India, through the WBCSD, have partnered with the IEA to elaborate a roadmap specifically for India. The roadmap has been technically supported and part-funded by IFC.

If current trajectories were to continue without intervention, by 2050, emissions from cement manufacture in India would reach between 488 $MtCO_2$ and 835 $MtCO_2$, a 255% to 510% increase compared to today's level. This roadmap aims to identify technologies (especially those with particular relevance to India), supportive policy frameworks and investment needs that could lead to direct emissions[6] reduction of about 0.28 tCO_2/t cement produced – *i.e.* from 0.63 tCO_2/t cement in 2010 to 0.35 tCO_2/t cement in 2050. Such a reduction in emission intensity would limit the growth in CO_2 emissions from the cement industry to between 100% and 240% compared to the current level.

This roadmap outlines an action plan for specific stakeholders to show the short- and longer-term priorities to reach such emissions reduction (see page 40). It also establishes a strategy to support industry in decoupling its expected future growth rates from growth in CO_2 emissions, primarily through the implementation of energy efficiency measures and equipment, switching to less CO_2-intensive energy sources, decreasing clinker-to-cement ratio and applying new technologies (where possible).

Such a low-carbon transition within the Indian cement industry would be impacted by and have impacts on other economic sectors, for example related to AFR availability. While the scope of this roadmap is the Indian cement industry, additional analysis should be undertaken to ensure that the levels of alternative fuels and blending materials envisaged in this roadmap would be available and sustainable. An analysis of the materials required and of the other sectors competing for the resources in India should also be undertaken.

Roadmap approach and scope

Roadmap partners

This roadmap has been developed by multiple partners (outlined on page 52) bringing specialised expertise from India and around the world. The IEA has overseen data analysis and modelling to understand the impact of the various levers identified on energy efficiency improvement and emissions reduction potential. Industry experts from the CSI companies across India have brought technical expertise from their own experience. The CII Sohrabji Godrej Green Business Centre has conducted a detailed survey on the cement industry data and brought specialised expertise in energy efficiency and alternative fuel use. The National Council for Cement and Building Materials (NCB) brought expertise in R&D and new technology to the drafting of the technical papers; and the CMA has been involved in the roadmap development process, and has helped validate the data used as being representative of the industry India-wide. IFC has part-funded the roadmap development as well as a further Phase II, outlined in Box 2 on page 7.

Roadmap drafting

The roadmap is based on a set of 27 technical papers developed by CII and NCB.[7] These papers, collectively titled *Existing and Potential Technologies for Carbon Emissions Reductions in the Indian Cement Industry* (WBCSD, 2012), outline the current status of each technology, the impact on energy consumption and anticipated benefits from implementation, the CO_2 reduction potential, main parameters influencing implementation, cost estimation, and the conditions, barriers and constraints of implementation. The papers have fed into the roadmap modelling by providing India-specific, up-to-date information on technology performances and costs, their benefits in terms of thermal and electrical savings, and their emissions reduction potential.[8]

5. The global *Cement Technology Roadmap 2009* is available at: www.wbcsdcement.org/technology and www.iea.org/roadmaps.

6. Direct emissions from cement manufacturing process. Does not include inderect emissions from the production of electricity.

7. The process of roadmap development can be found in Annex F.

8. The technical papers are available at: www.wbcsdcement.org/india-tech-roadmap.

Alongside the development of the technical papers, energy and emissions data were collected from 65% of the Indian cement industry through the CSI's Getting the Numbers Right (GNR) database[9] and detailed questionnaires to the industry. The results have been extrapolated and are considered to be representative of the India cement industry. These materials were used by the IEA to model potential impacts of each lever in relation to overall targets for emissions reduction. The model has been developed in response to the IEA 2°C Scenario (2DS) and its two variants, based on demand for materials: the Low- and High-Demand Cases (Box 1).

9. www.wbcsdcement.org/gnr.

Box 1: Scenarios used in this roadmap

The IEA *Energy Technology Perspectives 2012* (*ETP 2012*) uses extensive modelling to examine possible scenarios of global energy demand in the future, beginning with a simple extension of current trajectories and then identifying technology, policy and pricing options needed to reach specific targets at the lowest cost.

The 6°C Scenario (6DS), which serves as the baseline scenario for this roadmap, is largely an extension of current trends, with no effort on the part of government, industry or the general public to curb emissions. By 2050, global energy use in the 6DS almost doubles (compared with 2009) and total emissions rise even more. In the absence of efforts to stabilise atmospheric concentrations of greenhouse gas, average global temperature rise is projected to be at least 6°C in the long term. While autonomous energy efficiency is observed, this scenario expects no major shifts in technology or in the energy consumption mix for the industrial sector. As a result, global CO_2 emissions from all industry are 45% to 65% higher in 2050 than in 2010, and reach between 12.2 gigatonnes (Gt) of CO_2 and 13.7 $GtCO_2$ (IEA, 2012).

By contrast, the 2DS is target driven: it starts with the aim of limiting the increase in global average temperature to 2°C and examines how to achieve the deep emissions cuts (including CO_2 and other greenhouse gases such as methane and nitrous oxides) required to at least halve global emissions by 2050. This does not mean that industry needs to reduce its emissions by over 50%; rather, reaching this objective in the most cost-effective way requires each economic sector in each country to contribute, based on its costs of abatement. Under this scenario, annual global industrial emissions would be 6.7 $GtCO_2$ in 2050, about 20% less than current levels. For India, a detailed analysis was performed in collaboration with the India ETP expert group (IEA, 2011), and updated in *ETP 2012*. The analysis indicated that total industrial emissions would reach between 0.8 $GtCO_2$ and 1.1 $GtCO_2$ in 2050.

Given the recent global economic crisis and uncertainties about projecting long-term growth in materials consumption, two variants have been developed for each industry and for each scenario in the analysis presented in *ETP*: with materials being the product in demand, the text refers to a Low-Demand Case and a High-Demand Case. The difference in global materials production in 2050 for the Low- and High-Demand Case varies between 15% and 35% depending on the industry. Both the 2DS Low- and High-Demand Cases are driven by the same level of global CO_2 emissions reduction in 2050; the High-Demand Case requires greater reductions in emissions levels than the Low-Demand Case. As a result, costs are also higher in the High-Demand Case.

The scenarios are based on existing technologies, but take an optimistic view of further technology development and assume that new technologies are adopted as they become cost-competitive. They also assume that non-technical barriers are overcome, including social acceptance, proper regulatory frameworks and information deficits. The analysis does not assess the likelihood of these assumptions being fulfilled, but it is clear that deep CO_2 reductions can be achieved only if all sectors of society (industry, government, communities) contribute collectively.

These scenarios are not predictions. They are internally consistent analyses of pathways that may be available to meet energy policy objectives, given a certain set of technology assumptions.

This roadmap provides an outline of the potential emissions reduction, pricing and CO_2 abatement in the Indian cement industry from the 6DS to the 2DS, the ambitious yet necessary scenario the cement industry is aiming towards. Key performance indicators are shown only for the 2DS as this is the goal the cement industry in India aims to achieve.

Roadmap scope and boundary

This roadmap sets out one pathway by which the Indian cement industry can reach its targets to improve energy efficiency and reduce CO_2 emissions by 2050, thereby laying the foundation for low-carbon growth in the years beyond. Emissions reduction potential provided in this roadmap is based on direct emissions.

The roadmap focuses on the cement manufacturing process only from surface mining/quarrying[10] to the sale of cement to consumer, and discusses the energy and emissions reduction levers specific to the cement manufacturing process. Recognising the important contribution that CPP can provide in India both to enhance energy security and to reduce emissions, a section of this roadmap is dedicated to CPP. Yet, it is out of scope of the cement manufacturing process and so not included in the data modelling. Furthermore, while it is acknowledged that additional resource use and emissions are associated with the process of using cement in concrete, and concrete's eventual disposal, these aspects also fall beyond the scope of this roadmap. Similarly, locating the main clinkerisation unit near limestone deposits, transporting the clinker through ocean and rail networks, and locating cement grinding or cement-packing units near the fly ash or slag sources and near consumption centres – referred to as split located units – would reduce the carbon intensity through decreased emissions from transport of raw materials, blended materials and finished products. Split located units are increasingly being developed in India, but their impact on overall emission fall outside the boundaries of this roadmap.

CSI globally is undertaking detailed work to understand the use of concrete as a sustainable construction material and its potential role in improving the global efficiency of the building sector.

10. In India, "mine" refers to both open cast/surface mine (in Europe, this is "quarry") and underground mine.

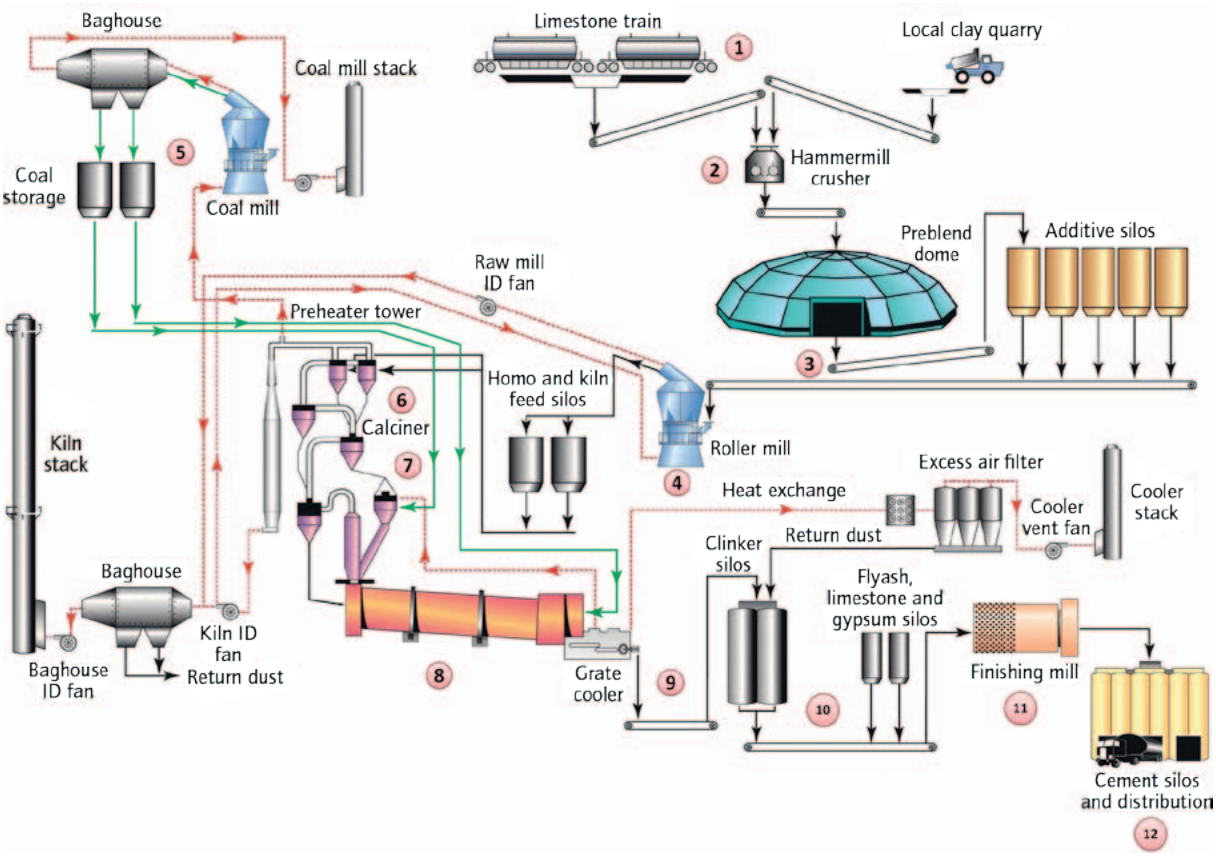
Box 2: Phase II: plant-level studies and technology implementation

This roadmap outlines potential CO_2 emissions reduction through the implementation of several levers in the Indian cement industry. These levers are based on a set of technical papers developed within the project. To better understand how such emissions reduction can be driven at a plant level, CSI members in India are undergoing a "Phase II" of the project, stemming from this roadmap. Phase II will include undertaking a detailed study to explore the resource efficiency opportunities at a manufacturing facility or plant level. The studies will be a combination of on-site work and desk study. These studies will identify various opportunities for resource efficiency (energy savings, material savings, renewable energy options, CO_2 emissions reduction, etc.) at a particular industrial facility. Enabled by partial funding and technical support from IFC, member companies of CSI in India are each overseeing a technical and economic assessment at one of their plants, to determine which of the technologies could be implemented and how. It is hoped that these studies, as well as in-depth studies on specific technologies, will lead to a fuller understanding of the potential benefits of implementing CO_2-reducing technologies at a plant level. The learning from this process will be shared among the industry and other stakeholders, resulting in public benefits in the cement industry (*e.g.* greenhouse-gas emissions reduction), primarily in India as well at a global level.

Overview of cement manufacturing

Cement is the essential "glue" in concrete, a fundamental building material for society's infrastructure around the world. There are two basic types of cement production process and a number of different kiln types. These are referred as either "wet" or "dry", depending on the water content of the raw material feedstock. The wet process consumes more energy to evaporate the 30% plus slurry water before heating the raw materials to the necessary temperature for calcination.

Figure 1: Cement manufacturing at a glance: dry process kiln with calciner



Notes: Figure 1 shows dry cement process. 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).

Source: Adapted from diagram by HeidelbergCement Group.

The cement manufacturing process is complex, involving multiple steps that require specialised equipment. Energy input is required at every stage, and various processes lead to emissions of CO_2 and other greenhouse gases. Thus, a roadmap focusing on improving energy efficiency and reducing emissions must carefully examine opportunities at each step of the process.

1. Surface mining/quarrying raw materials

Naturally occurring calcareous deposits, such as limestone, marl or chalk, provide the calcium carbonate ($CaCO_3$) that comprises the raw materials of cement. As these are extracted from surface mines/quarries, a first consideration in energy efficiency is often to locate cement plants close to the source of raw material.

2. Crushing

After the raw material is mined and transported to the cement plant, the first step is to feed it through the primary/secondary crushers, which break it down into pieces approximately 10 centimetres (cm) in size.

3. and 4. Prehomogenisation and raw meal grinding

Prehomogenisation is a process by which different raw materials are mixed to obtain the chemical composition required for the end use of a given "batch" of cement. 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 of cement manufacturing. 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.

5. Coal grinding/kiln fuel preparation

Coal is ground into fine powder to enable it to feed into the kiln as a fuel, to generate the required heat for calcination.

6. Preheating

One means to improve the efficiency of the process is to pre-heat the raw meal before it enters the kiln, which stimulates faster chemical reactions. A pre-heater is a series of vertical cyclones through which the raw meal is passed, coming into contact with swirling hot gases moving in the opposite direction. As these gases are exhaust from the kilns, efficiency is gained by using heat generated by one production process to provide energy needed for another. Depending on the moisture content of the raw material, a kiln may have up to six stages of cyclones with higher temperatures – obtained through increased heat recovery – at each extra stage.

7. Precalcining

Calcination is the decomposition of limestone to lime. The required reactions, which also need heat energy inputs, are stimulated at two points in the manufacturing process: within the "precalciner", a combustion chamber at the bottom of the pre-heater above the kiln, and within the kiln itself. This is the first point of the manufacturing process at which emissions are produced: the chemical decomposition of limestone typically accounts for 60% to 65% of total emissions. The fuel combustion needed to generate heat in the precalciner also produces emissions, accounting for about 65% of the remainder of total emissions.

8. Clinker production in the rotary kiln

The precalcined meal then enters the kiln, where intense heat – up to 1 450°C – causes chemical and physical reactions that partially melt the meal into "clinker", an intermediate product in cement manufacturing that becomes the main substance in cement and is commonly traded. Fuel is fired directly into the kiln: as the kiln rotates, about three to five times per minute, the material slides and tumbles down towards the flame, through progressively hotter zones.

9. 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 facilities between clinker production and the plant components that handle blending and/or grinding.

10. Blending

Increasingly, cement producers are using materials such as slag, fly ash, limestone or other mineral components to reduce the amount of clinker required for a given batch of cement. In such cases, the end product is called "blended cement"; it can be customised to provide characteristics needed for the end-use. For example, all cement types contain around 4% to 5% gypsum to control the setting time of the product.

11. Cement grinding

The cooled clinker and/or blended mixture is ground into a grey powder, known as Ordinary Portland Cement (OPC), or ground with other mineral components to make blended cement. Traditionally, cement plants used "ball mills" for grinding. Today, more efficient technologies – including roller presses and vertical mills – are used in many modern plants. Wider deployment could further improve efficiency of the industry as a whole.

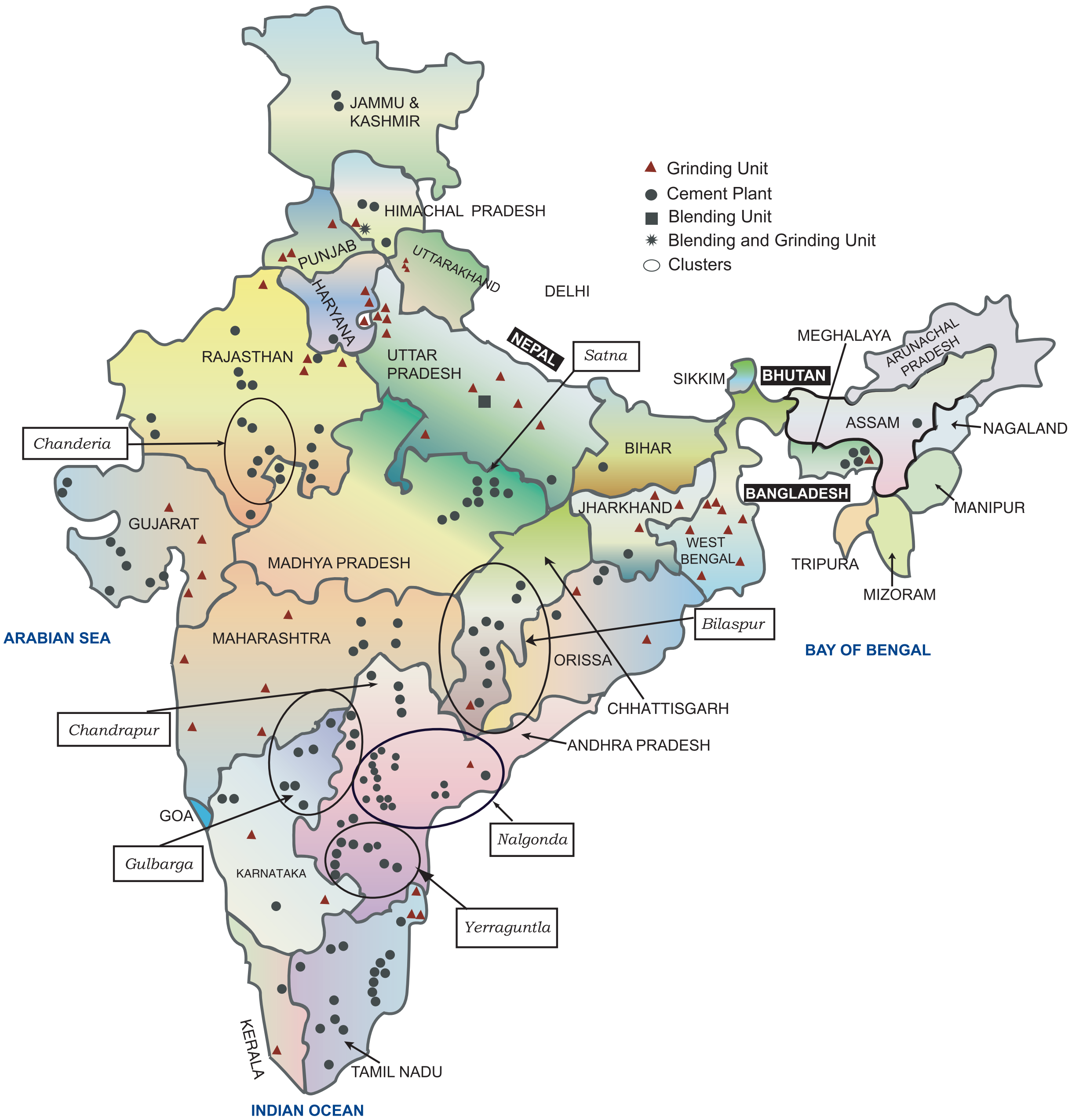
12. Storing in the cement silo

Once homogenised, the final product is stored in cement silos, ready to be dispatched either to a packing station (for bagged cement) or to a silo truck.

Indian cement manufacturing at a glance

The Indian cement industry is the second-largest in the world, after China. In 2010/11, about 183 large cement plants were in operation, owned by over 40 companies across India (Figure 2). In 2012, total installed capacity is around 320 Mt. Average kiln capacity is currently 4 500 tonnes per day (tpd), with the largest kilns reaching a capacity of 13 500 tpd. Small cement plants in India account for a small share of the total installed capacity (less than 5%). About 20% of WHR potential in the country is tapped – *i.e.* 110 megawatt (MW) of an estimated overall potential of around 555 MW – and about 60% of the power requirement for cement manufacture in India is from CPP.

Figure 2: Indian cement industry



This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

Source: Adapted from Cement Manufacturers' Association Basic Data 2012.

Annual production of cement in India rose from 95 Mt in 2000 to about 220 Mt in 2010, an average increase of almost 10% per year. Three main factors have prompted this growth: the real estate boom since 2004; increased investments in infrastructure by both the private sector and government; and higher government spending on various social programmes (which often require construction). Despite this strong growth, the 2010 cement consumption of 188 kilogrammes per capita (kg/capita) is one of the lowest in the world and less than half of the global average of 450 kg/capita. Although the energy intensity per tonne of product for cement manufacturing is less than that of other energy-intensive materials (such as aluminium and steel), the volume of production is much higher. At present, the cement industry is the third-largest energy consumer and second-largest CO_2 emitter in India's manufacturing sector. It produces approximately 7% of India's man-made CO_2 emissions.[11]

Based on the technology characteristics and data available from large cement producers, the thermal and electrical efficiencies of India's cement production clearly surpass the world average. The Indian industry's average thermal energy consumption is estimated to be about 725 kilocalories (kcal)/kg clinker (3.04 gigajoules [GJ]/t) and the average electrical energy use is about 80 kilowatt hour (kWh)/t cement, much lower than the global average of 934 kcal/kg clinker (3.9 GJ/t) and 107 kWh/t cement. As accessible limestone reserves in India are limited, particularly for high-grade limestone; the primary raw material used is a low-grade limestone with a fairly low $CaCO_3$ content compared to that used in other countries. This means that the raw materials have to be used as completely and efficiently as possible. The "burnability" of this low-grade limestone is very easy.

Future projections for population growth and economic development in India will drive a rapid increase in demand for concrete, highlighting the urgent need to bring energy consumption and emissions under control.

11. For more information on specifics of the Indian cement industry, refer to the report *Technical Papers for the Indian Cement Industry - Looking Behind the Data*, by the European Cement Research Academy (ECRA, 2012) available from www.wbcsdcement.org/india-tech-roadmap.

Efforts towards low-carbon cement production in India

Almost 99% of the installed capacity in India uses dry process manufacturing, and about 50% of capacity has been built in the last ten years. The industry has been adopting the latest technologies for energy conservation and pollution control, as well as online process and quality control based on state-of-the-art automation systems. However, co-generation of power and heat through WHR, AFR utilisation, and technologies for low nitrogen oxide (NOx) emissions have not penetrated significantly. The power demand required for various emission abatement technologies in India is fairly low compared to other regions for example Europe.

Coal is the major fuel stock for cement production in India, primarily because it is a readily available and low-cost domestic resource. However, Indian coal is of lower quality than most coals found elsewhere: the typical calorific value is 4 400 kcal/kg (18.4 megajoules [MJ]/t) – in Europe, cement plants use bituminous coal with calorific values of around 6 162 kcal/kg (25.8 MJ/t) and petcoke of around 7 762 kcal/kg (32.5 MJ/t). In India, petcoke (produced in Indian refineries) accounts for 10% to 15% of fuel used: it has a higher calorific value (*i.e.* provides more energy per unit) but also a high sulphur content (resulting in higher sulphur oxide emissions). Imported coal is used if required, but is significantly more expensive.

The Indian cement industry's efforts to reduce its carbon footprint by adopting the best available technologies and environmental practices are reflected in the achievement of reducing total CO_2 emissions to an industrial average of 0.719 tCO_2/t cement in 2010 from a substantially higher level of 1.12 tCO_2/t cement in 1996.

Yet opportunity for improvement exists, particularly in relation to five key levers that can contribute to emissions reduction:

- alternative fuel and raw materials (AFR);
- thermal and electrical energy efficiency;
- clinker substitution;
- waste heat recovery (WHR); and
- newer technologies.

Alternative fuel and raw materials: to date, AFR use is a very low 0.6% of thermal energy across India, compared to a global average of about 4%, but the cement industry has increased its focus on

AFR utilisation by using newer industrial, municipal and agricultural wastes. Substantial scope exists to enhance waste utilisation, particularly hazardous and combustible wastes. Indian waste policy, however, does not support co-incineration of waste by industry, so permitting procedures can be difficult, and public acceptance of this practice is low. Moreover, logistics to transport AFR from the site of generation to cement plants is often complex. However, recognising this as a key lever for CO_2 emissions reduction, the industry is working to achieve international best practices of waste utilisation.

Thermal and electrical energy efficiency: the best levels of specific energy consumption achieved by some Indian cement plants, at 680 kcal/kg clinker (2.85 GJ/t) and 66 kWh/t cement, are comparable with the best in the world. A number of plants installed before the 1990s have been modernised to a limited extent by retrofitting with new technologies. However, they need to prioritise bringing specific energy consumption levels closer to the best achieved levels in the Indian industry by further modernisation and adoption of best available processes and technologies.

The Indian cement standards as outlined by the Bureau of Indian Standards (BIS) are appropriate for the national context with respect to market, available materials and ambient conditions. The testing and standard requirements means cement producers in India can fulfil required quality specifications at a cement fineness which is somewhat lower than the fineness at which cement is ground in other regions of the world. The easy burnability of the raw meal across India allows the Indian cement industry to coarsely grind the material. In addition, the grinding equipment used is predominantly new and modern. The combination of these factors leads to high energy efficiency in the raw material and cement grinding phase.

Clinker substitution: through adoption of waste utilisation processes, *i.e.* using other industries' by-products or waste within the cement manufacturing process, the industry is decreasing its use of carbon-based raw materials. Production of blended cements, such as Portland Pozzolana Cement (PPC) and Portland Slag Cement (PSC) is increasing year on year. In 2010/11, the blended cement percentage was as high as 67% of total cement produced, compared to only 37% in 2000/01.

For use in blending, fly ash has to be ground because it is delivered quite coarse from the power plants and is mainly inter-ground directly with the clinker. The combination of grinding and blending characteristics, and standards in India, result in more cement being needed per cubic metre of concrete than in other countries in the world.

Waste heat recovery: the adoption of WHR systems in Indian cement manufacturing facilities has been relatively slow compared to other countries. Out of about 183 large cement kilns in the country, only 12 have adopted WHR systems. The high initial investment is currently deterring manufacturers from adopting WHR systems.

Newer technologies: several newer technologies are under various stages of development and hold promising reduction potential for the future.

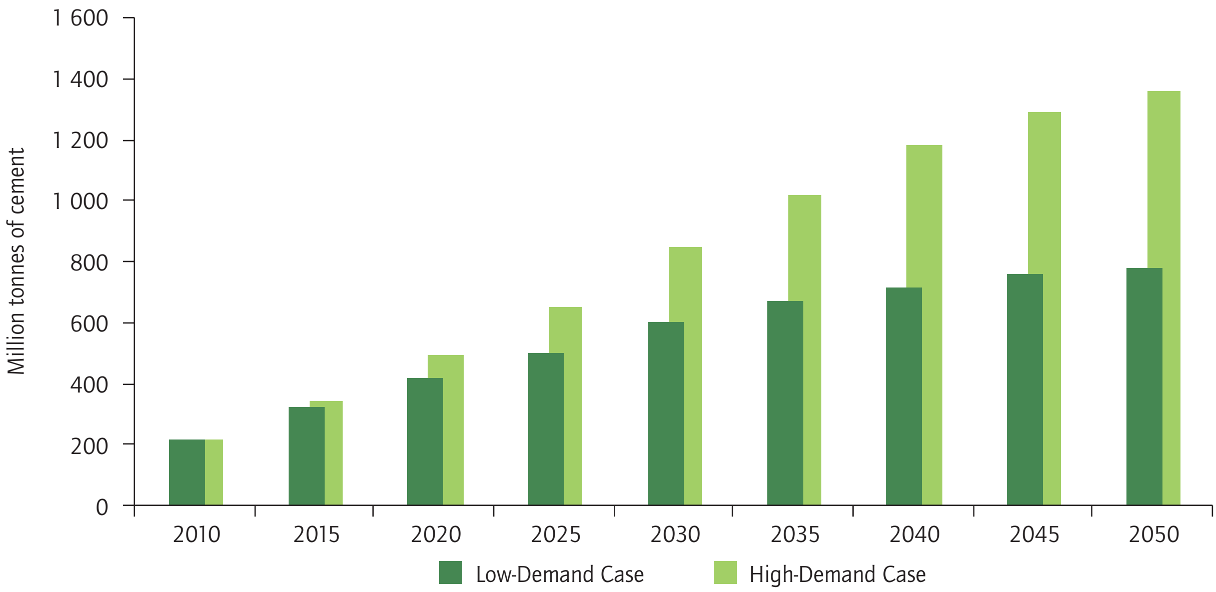
Vision for deployment to 2050

India's population is set to increase by almost 40% between 2010 and 2050; from 1.2 billion to 1.7 billion in 2050. Over the same period, the rapid urbanisation seen recently is expected to accelerate: from 380 million people in urban areas in 2010 to an estimated 675 million by 2050 (UN DESA, 2011). Gross domestic product (GDP) is expected to increase from USD 4 060 billion in 2010 to USD 37 721 billion in 2050. These trends will drive up demand for concrete in the building sector. The other main driver of this growth is the expected large-scale infrastructure development such as ports on the western coast, dams in the northern mountainous regions, and airports in the growing metropolitan areas. Climate change adaptation and mitigation measures are also expected to increase concrete use in India. While the growth in cement demand and production in the country is expected to slow down between 2030 and 2050, the rate of cement demand will continue to increase.

The growth in domestic cement demand is expected to remain strong, rising to between 465 kg/capita and 810 kg/capita in 2050.[12] Annual cement production is estimated to reach between 780 Mt and 1 360 Mt by 2050 (Figure 3). Under the latter, which reflects the High-Demand Case, India could become the world's largest cement producer before 2050.

12. For more detail on assumptions and modelling framework, please refer to Annex D.

Figure 3: Projected growth of cement production in India

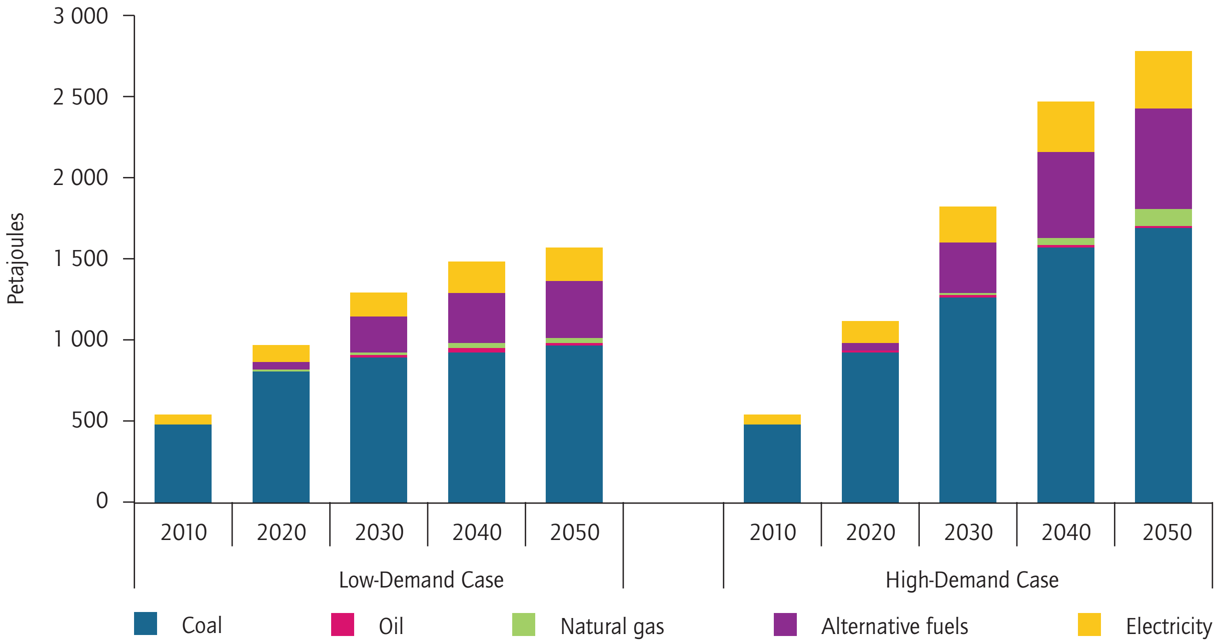


KEY POINT: Cement production is projected to increase between 3.6 and 6.3 fold between 2010 and 2050.

Obviously, both rates of increase in production will have a strong impact on the overall energy consumption of the cement industry, but the differences are substantial. Under the 6DS, production and energy consumption would increase at a similar rate: about 3.2% per year in the Low-Demand Case and 4.6% per year in the High-Demand Case. By contrast, under the 2DS, the annual increase in energy consumption would be limited to between 2.7% (Low-Demand Case) and 4.1% (High-Demand Case) (Figure 4). Importantly, the energy mix in the two scenarios is quite different. In the 6DS, fossil fuels (mostly coal) account for almost all (99%) of the thermal energy consumption in 2050, whereas their share drops to 75% in the 2DS with AFR accounting for 25%.

While the use of alternative fuels will help reduce the carbon intensity of the cement industry, some of these sources have lower energy content and higher moisture levels than commercial fuels. Thus, they may actually increase the required input of energy; in some cases, extra energy may be required to treat the AFR before feeding it into the cement kilns.

Figure 4: Final energy consumption by energy source in the 2DS



KEY POINT: Energy consumption in the cement sector between 2010 and 2050 is expected to grow between 2.8 and 5.0 fold.

The relatively low increase in energy consumption compared to cement production in the 2DS is explained, in part, by improvements in energy efficiency and a lower clinker-to-cement ratio. The 6DS already takes into account anticipated energy efficiency improvements without intervention, while the 2DS reflects concerted effort to achieve the aim, by 2050, of reducing the average electric intensity of cement production to 70 kWh/t cement and the average thermal intensity of clinker production to about 680 kcal/kg clinker (2.85 GJ/t clinker) (Table 1). These improvements in energy intensity occur despite the increase in the share of alternative fuels to about 25% of total cement thermal energy consumption and the application of carbon capture technologies.

Table 1: Key indicators for Indian cement industry in the 2DS

		Low-Demand Case			***High-Demand Case***		
	2010	**2020**	**2030**	**2050**	**2020**	**2030**	**2050**
Production (Mt)	217	416	598	780	492	848	1 361
Per-capita consumption (kg/capita)	188	309	400	467	364	565	812
Clinker-to-cement ratio	0.74	0.70	0.64	0.58	0.70	0.64	0.58
Electric intensity of cement production (kWh/t cement)	80	76	73	71	75	72	70
Thermal intensity of clinker production (kcal/kg clinker)	725	709	694	680	703	690	678
Alternative fuel use (as a share of thermal energy consumption) (%)	0.6	5	19	25	5	19	25

Notes: Data for 2010 is for financial year 2009/10 ending 31 March 2010. The electric intensity of cement production does not include the reductions that may come from the use of WHR.

From the five levers considered – AFR, thermal and electrical efficiency, clinker substitution, WHR, and newer technologies – only three will play a role in restraining the growth in energy consumption in the Indian cement industry. Clinker substitution and thermal efficiency will be the main contributors to the energy savings, while WHR provides more moderate results (Table 2). AFR is not expected to reduce energy consumption, and some newer technologies *e.g.* CCS, do not contribute to energy savings. Other newer technologies such as nanotechnology are not expected to be commercially available by 2050.

For AFR and CCS, the more important gains are the savings they will generate in CO_2 emissions, either within or beyond the cement industry boundary. But this may carry a cost: because it needs energy inputs to operate, CCS could, in fact, increase the overall energy requirement of the cement industry (*i.e.* it carries an "energy penalty" for plant operation).

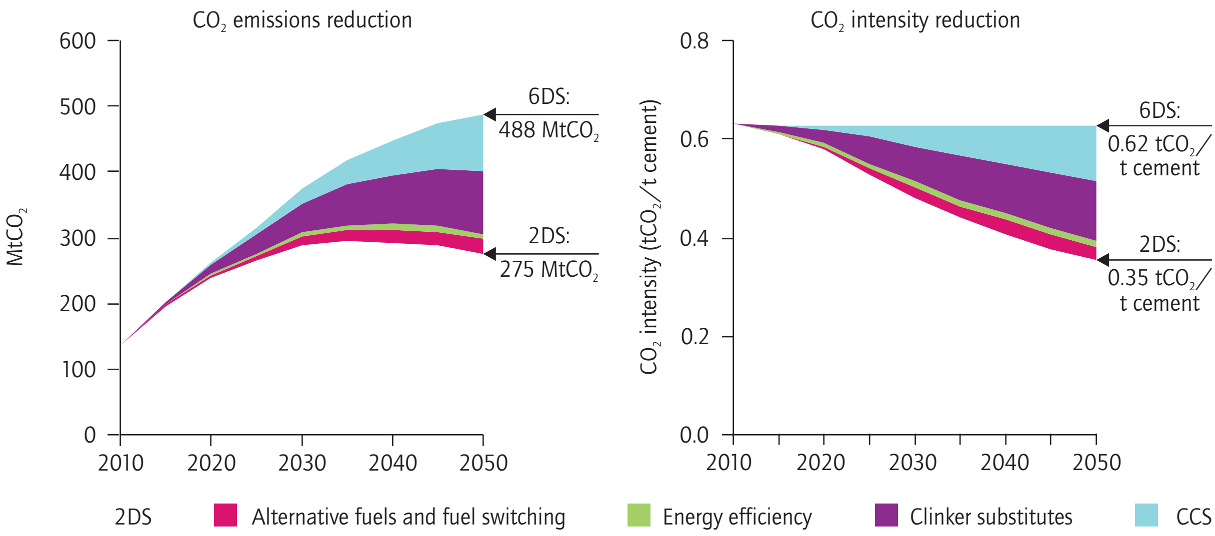
As the levers interact, the sum of energy savings from the levers as a group is higher than the total of the potential energy savings delivered by each. For example, an increase in the clinker substitution will lower the thermal energy requirements; and a subsequent improvement in thermal energy efficiency would then have a smaller overall impact as the need for fuels will be lower. The higher improvements in the High-Demand Case are explained by the higher share of new plants, which are more efficient than existing ones, compared to the Low-Demand Case.

Table 2: Potential energy savings from implementation of the different levers

	Savings from 6DS to 2DS							
	Low-Demand Case				*High-Demand Case*			
	2020	2030	2040	2050	2020	2030	2040	2050
Total energy reduction (PJ)	65	196	304	377	77	235	395	485
Additional energy required for CCS (PJ)	6	40	80	111	10	64	157	221
Net energy reductions (excluding additional energy required for CCS) (PJ)	71	237	384	488	87	298	553	706
Reductions (PJ) from:								
Thermal energy efficiency	16	48	78	96	18	47	77	97
Electrical energy efficiency	5	12	18	22	3	4	6	8
Waste heat recovery	1	8	15	20	2	15	30	39
Clinker substitution	49	174	288	373	88	250	455	583

Direct CO_2 emissions in the industry can be significantly reduced through a combination of clinker substitution, the use of AFR, energy efficiency and CCS (Figure 5). When taken in isolation, thermal efficiency contributes to a reduction of 0.03 tCO_2/t cement to 0.05 tCO_2/t cement between 2010 and 2050. However, several factors offset the contribution of thermal energy efficiency to reduced direct emissions including the application of CCS, which increases energy consumption. But with increased use of alternative fuels and clinker substitutes, and with the application of CCS, CO_2 intensity in the 2DS can reach 55% of the intensity in the 6DS; from 0.62 tCO_2/t cement in 2050 to 0.35 tCO_2/t cement in Low-Demand Case. Despite the important improvement in CO_2 intensity, emissions are expected to be two times higher in 2050 than in 2010 due to the 260% production growth.

Figure 5: Direct CO_2 emissions and intensity reduction by each technology in the Low-Demand Case



Notes: Includes only direct CO_2 emissions from cement manufacturing; indirect emissions from the use of electricity are not taken into account.

KEY POINT: Total savings between the 6DS and 2DS amount to 212 MtCO$_2$.

Carbon emissions reduction levers

Several independent studies have recently been carried out which include implications for low-carbon growth of the Indian cement industry. The *Interim Report of the Expert Group on Low Carbon Strategies for Inclusive Growth* (GoI, 2011); the *Challenge of the New Balance* (Centre for Science and Environment, 2010), and the *Low-Carbon Roadmap for Indian Cement Industry* (CII, 2010) evaluate options for the Indian cement industry to pursue a low-carbon path, and confirm the findings of several other studies (*e.g.* McKinsey, 2010; ECRA, 2009) that broadly highlight five major emission reduction levers (for both direct and indirect emissions):

- **Alternative fuels and raw materials**: promoting use of industrial wastes, sorted municipal waste and biomass to offset carbon-intensive fossil fuels and natural raw materials. AFRs include wastes that would otherwise be burnt in incinerators, land-filled or improperly destroyed.
- **Thermal and electrical energy efficiency**: deploying existing state-of-the-art technologies in new cement plants, and retrofitting with energy efficient equipment in existing plants where economically viable.
- **Clinker substitution**: increased use of blending materials (*i.e.* raw materials other than limestone) and increased production of blended cement, both offering a reduction of carbon-intensive clinker (an intermediate in cement manufacture) in cement.
- **Waste heat recovery**: adopting WHR technologies to convert thermal energy, otherwise lost in cement manufacture, to electricity, partially offsetting the electrical energy requirement in the cement manufacturing process.
- **Newer technologies**: focusing on emerging technologies such as carbon capture, energy crop plantation and carbon capture through the growth of algae.

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 excess air consumption and higher moisture levels). Therefore simply adding up the reduction potentials of each technology in order to calculate total potentials is not feasible. The linkages between each lever, and the combination that would lead to highest emissions reduction for each specific plant, must be clearly understood during Phase II technology assessments (see Box 2 page 7).

Technology: co-processing of alternative fuels and raw materials (AFRs)

Fossil fuels and raw materials used by Indian cement plants can be replaced to a large extent with AFR. The carbon intensity of the fuel will depend on the extent of usage of AFR in the total fuel used by the cement plant. Use of AFR in cement kilns creates a win-win situation for the cement industry and also for other stakeholders (waste generators, local administration and the society). As well as contributing to reduced emissions, effective solid waste management practices from India's growing urban population and from other industries has become imperative for the sustainable growth of the country, as identified in the Prime Minister's National Action Plan on Climate Change (NAPCC) – National Mission on Sustainable Habitat. It is widely accepted that cement kilns are particularly well-suited to manage different kinds of wastes by using them as AFR, considering the high temperature and long residence time available in the cement kiln. Life-cycle assessment (LCA) shows that co-processing of waste as AFR in the cement kiln has a much lower environmental impact than disposal through incineration or landfill.

The global average alternative fuel use in the cement industry is currently 4.3% of total thermal energy consumption. In some countries, the average use is as high as 30%, whereas in India the average is 0.6%. With extensive national and global expertise available, the Indian cement industry is technically ready to adopt higher rates of AFR use. The *Interim Report of the Expert Group on Low Carbon Strategies for Inclusive Growth* (GoI, 2011) proposes fuel substitution and highlights corresponding emission intensity reduction that can be achieved by 2020. Under the report's Determined Effort Regime, a fuel substitution rate of 5% is expected in the cement industry by 2020. Under the Aggressive Effort Regime, fuel substitution with the adoption of newer technologies could increase to 10%, and the adoption of BAT by smaller units could lead to an annual decrease in emission intensities of 1.8%.

Typical wastes streams that can be used as AFR in the Indian cement industry include:

- industrial wastes;
- pre-processed industrial wastes;
- sorted municipal solid waste (MSW);
- refuse-derived fuel (RDF) from MSW;
- discarded tyres and tyre chips;
- expired consumer goods *e.g.* medicines and fast-moving consumer goods (FMCG);
- waste oils and solvents;
- non-recyclable plastics, textiles and paper residues;
- biomass (such as rice husk, coconut shells and groundnut shells);
- effluent treatment sludges from water and wastewater treatments plants; and
- lime sludges from paper and allied industries.

Although AFR as a lever for CO_2 reduction offers a large potential to the Indian cement industry to reduce its carbon footprint, it's use is a complex process and must be managed successfully. To ensure availability and consistency of alternative fuel quantity and quality, waste legislation in the country should enable effective waste collection, treatment and processing. The pricing of waste must ensure waste minimisation at source (to reduce disposal costs for waste generators) as well as zero or negative cost to cement manufacturers (encouraging them to install the expensive handling, storage and firing facilities at their premises) for increased thermal substitution rate (TSR).[13]

Several important, yet straight-forward procedures must be in place to ensure correct use of AFR. Appropriate planning and adequate preparations must be carried out, and the potential and properties of AFR use must be understood, to ensure no decrease in productivity, or increase in emissions of basic and hazardous pollutants. Only carefully selected waste with recoverable calorific or material value are suitable for use as alternative fuels or raw materials. These AFRs can be used in facilities that employ the highest environmental practices and best available techniques, and in which installed plant equipment can handle the alternative fuels well and burn them fully. Adequate quality control systems must be strictly adhered to for any materials used (whether conventional or alternative) to support proper monitoring and management of the effects on kiln operation, emissions, and the quality of the clinker, cement and the final product.

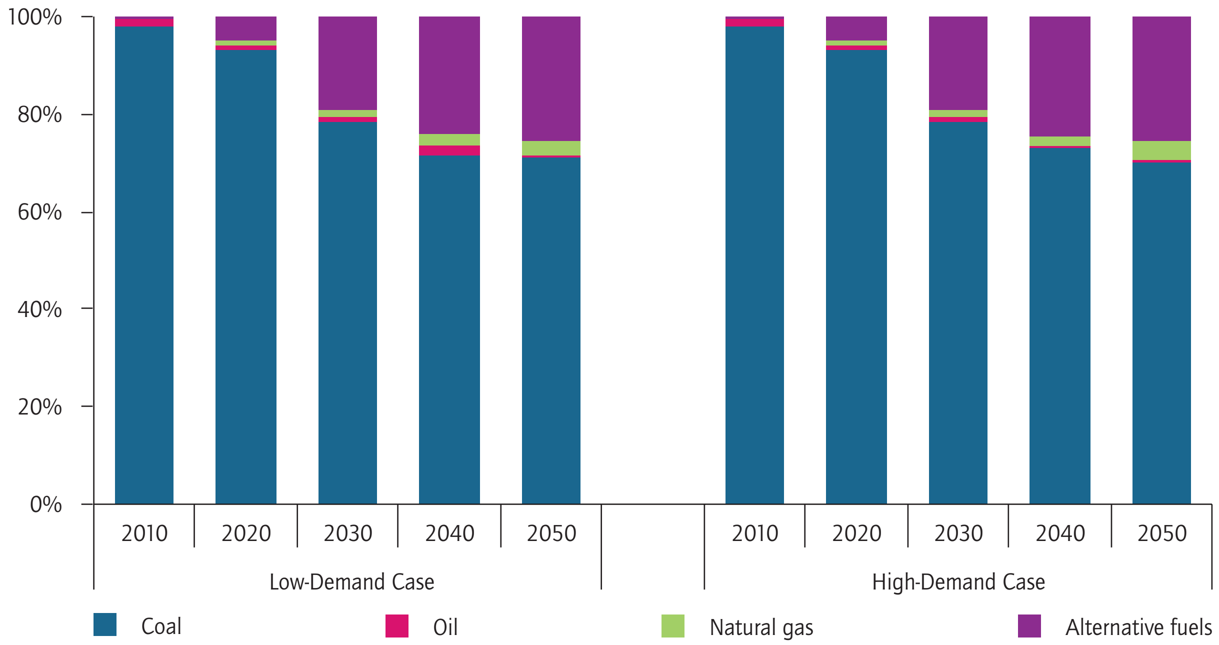
Such quality control is imperative as many of the elements in conventional raw materials and fuels (such as metals, halogens and organic compounds) are also found in wastes used as AFR. The legislation for AFR should be developed to focus on emission limits rather than the input characteristics of waste, which could be managed by the cement plant by dilution to ensure stable process conditions, product quality and adherence to emissions regulations. Emission monitoring frequency for AFR use in cement kilns must be regulated. Regulations are already in place in many countries, including the United States Environmental Protection Agency (US-EPA) Boiler and Industrial Furnace (BIF) regulation (US-EPA, 2001) and the European Union (EU) Directive 2000/76/EC (EU, 2000). There is an urgent need to implement appropriate policies and practices in favour of increased alternative fuel use in India.

The use of AFR in the 2DS is expected to increase from 3.1 PJ today, to between 347 PJ and 613 PJ in 2050; an average annual increase of 12% (Low-Demand Case) and 14% (High-Demand Case) over the 2010 to 2050 period. The use of AFR would account for about 25% of the total cement thermal energy consumption by 2050 (Figure 6). While it is possible to achieve such an increase in the use of AFR, significant competition for limited biomass and resources, and for industrial and post-consumers waste from other sectors, may lead to increased costs and possibly make industrial application less attractive.

Given the wide range of waste that can be used as AFR, and their different moisture and heat content, and given the different fuels that can be displaced by the use of alternatives, the impact of AFR on total electrical and thermal energy consumption can be hard to quantify. However, their use may have an important impact in reducing the carbon footprint of the cement industry. It is estimated that AFR can contribute to a reduction of between 21 $MtCO_2$ (Low-Demand Case) and 37 $MtCO_2$ (High-Demand Case) in the 2DS compared to the 6DS by 2050.

13. Thermal substitution rate is the percentage of energy from conventional fossil fuels which can be replaced by a lower carbon energy source.

Figure 6: Share of thermal energy use in the cement industry by energy source in the 2DS



KEY POINT: By 2050, use of AFR is projected to account for 25% of total thermal energy consumption in the cement sector.

Challenges to implementation

Cement kilns can, theoretically, operate at 100% TSR, which would in turn offset the need for some primary fossil fuels and natural raw materials, for example limestone. However, several other enabling factors, such as an appropriate policy framework, systems to collect and segregate waste, pre-processing and blending facilities, and the availability of alternative fuels without technical limitations need to be in place. Cement kilns can also exhibit significantly varying behaviour depending on the kiln capability and the type of AFR co-processed. The cement industry needs to disseminate adequate technical competence to co-process different kinds of AFR at workable levels.

Increased TSR in the Indian cement industry would be possible if:

- **waste legislation in India specifically supports co-processing** – considered as more environmentally sustainable than other methods of disposal and also being a recovery operation – as the preferred choice of waste disposal;
- **availability and consistency of alternative fuel quantity and quality is rapidly increased** by an effective collaboration between waste generators and the cement industry, and efficient collection, segregation, transportation and processing of waste in a manner acceptable to the cement industry for both quality and cost;
- **alternative fuels are priced properly** to encourage cement manufacturers to install the (expensive) handling, storage and firing facilities at their plants; and
- **social acceptance of using wastes** (such as municipal or hazardous waste) as AFR in cement kilns **is improved** through appropriate awareness and governing mechanisms by the government and by non-governmental organisations (NGOs).

Research and development needs and goals

Successful switching to AFR from conventional fuels presents some challenges that must be addressed. To use AFR in kilns safely and cleanly, suitable materials must be identified and classified,

Table 3: Partner roles (AFR)

Item/ Partner	Cement industry	Equipment suppliers	Government	Universities/ academia	Research institutions	Industry associations
Best practices	✓	✓₹	₹			✓
Technology research	✓₹	✓₹	✓₹	✓	✓	
Technology diffusion	✓	✓₹				✓
Institutional structure	✓	✓	✓₹	✓	✓	✓
Performance data	✓			✓		✓

Notes: ✓= leadership role and direct involvement required; ₹ = funding source.

Table 4: Potential impacts (AFR)

Parameter/ Impact	Low	Medium	High
Energy savings			
Carbon savings			
Cement production			
Investment needs			

and research needs to identify the right feed point for the specific AFR material, based on the appropriate conditions required for complete combustion. It will also be necessary to simulate the likely emissions of any specific material in any given combustion condition. Information based on R&D already undertaken to identify the operational health and safety (OH&S) risks of AFR – and how to avert them – must then be communicated broadly to all stakeholders.

Technology: thermal and electrical energy efficiency

The Indian cement industry has been growing at a rapid pace during the late 20th and early 21st centuries; about 50% of Indian cement industry's capacity today is less than ten years old. While building these new cement plants, manufacturers have installed the latest, energy efficient technologies by design. As a result, recent cement plants achieve high levels of energy efficiency performance. With electricity tariffs for industry in India being among the highest in the world, implementing such energy efficiency measures at the design stage provides significant advantage to the cement manufacturers by lowering energy and production costs. Increasing energy costs also prompted owners of older manufacturing facilities to adopt gradually the latest energy efficient technologies and improve their energy performance.

A gradual, yet significant, improvement is evident in the Indian cement industry's average energy efficiency performance. The Indian cement industry has phased out several old technologies in the 1990s and 2000s. Out of about 183 large cement manufacturing facilities in the country, only three facilities still operate with wet kilns (includes wet and semi-dry) and six facilities have older model coolers (such as rotary and planetary clinker coolers).

The thermal efficiency of an installation is largely defined by its original engineering design. After installation, however, adequate machinery maintenance and operation are essential to ensure the maximum potential efficiencies are achieved during operation. 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 technology combines the dry manufacturing process with preheater and precalciner technology and the latest generation clinker cooler.

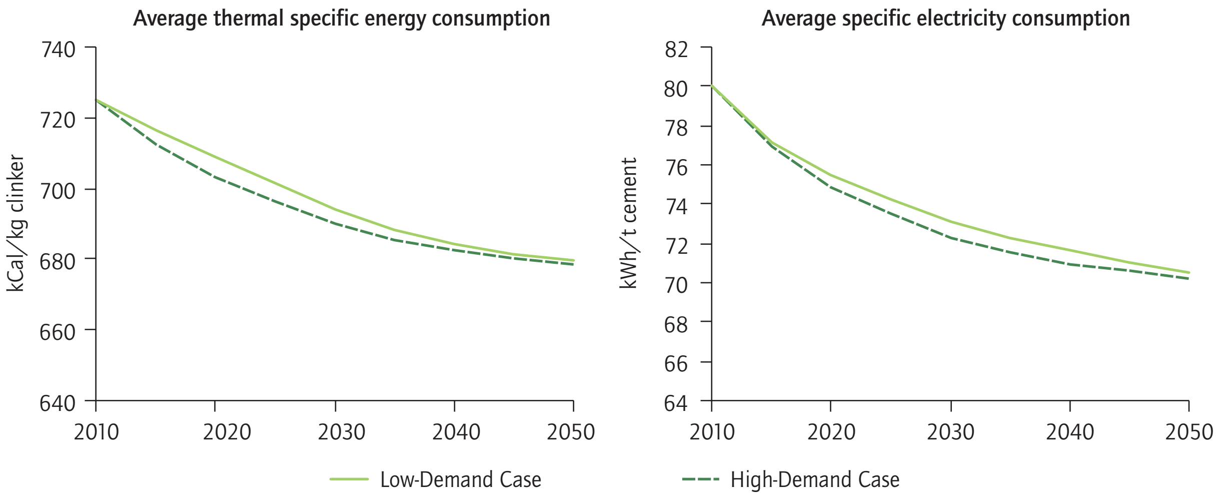
As cement plants in India are already among the most efficient in the world, efficiency is expected to remain relatively constant in the 6DS; thermal efficiency will improve from 725 kcal/kg clinker (3.04 GJ/t clinker) in 2010 to between 720 kcal and 704 kcal/kg clinker (3.01 GJ and 2.95 GJ/t clinker) in the Low- and High-Demand Cases in 2050. Electricity efficiency will improve from 80 kWh/t cement in 2010 to between 78 kWh and 72 kWh/t cement in 2050. The higher improvements in the High-Demand Case are explained by the higher share of new plants compared to the Low-Demand Case.

The picture that emerges from the 2DS is quite different (Figure 7); specific energy consumption would reach about 680 kcal/kg clinker (2.85 GJ/t clinker) and about 70 kWh/t cement in 2050. If India were to follow the path of the 2DS for specific energy intensity, and if all other factors are kept constant, about 100 PJ of energy and between 2 000 gigawatt hour (GWh) and 6 000 GWh of electricity would be saved compared to the 6DS. Given the expected production growth, and assuming a constant average emission factor for the cement industry, this improvement between the 6DS and 2DS would result in direct CO_2 emissions savings of about 25 $MtCO_2$ in 2050.

Challenges to implementation

Theoretical minimum thermal energy consumption for chemical reactions in the cement manufacturing process is about 390 kcal/kg clinker to 420 kcal/kg clinker (1.63 GJ/t clinker to 1.76 GJ/t clinker). This minimum requirement is established based on the raw material composition needed to achieve desired phases in clinker formation. The actual thermal energy consumption is higher than the theoretical minimum, considering certain processes and equipment design. Some heat loss in the system is unavoidable (either not technically feasible or not economically viable to recover fully) such as heat loss through kiln or calciner surfaces, and economic thickness of refractory/insulation.

Figure 7: Projected specific electrical and thermal energy consumption in the 2DS



KEY POINT: Even though Indian cement plants are among the most efficient in the world, noticeable improvements in energy efficiency are still possible.

Specific thermal and electrical energy consumption depends on factors such as efficiency of equipment used in the market, mode of material transfer across the manufacturing process, extent of process automation, and quality of raw material and fuels. Some of the barriers that inhibit the industry from reaching even lower levels of energy consumption are:

- **cost**: a significant decrease in specific energy consumption of older cement manufacturing facilities will only be achieved through major retrofits, which often have high investment costs that are financially unviable;
- **environmental requirements**: environmental policies to mitigate important negative environmental impacts are becoming more stringent in India, resulting in increased specific energy consumption – for example, through installation of bag filters instead of electrostatic precipitators, mechanised loading/unloading systems for suppressing fugitive dust emissions and installation of new emission controls for NOx;
- **demand for OPC**: production of OPC requires significantly more specific energy than other types of cement; and
- **increased use of alternative fuels**: in cement manufacture, this generally increases specific energy consumption (*e.g.* because of a higher air requirement and higher moisture levels). However, the overall lower CO_2 emissions through increased use of alternative fuels outweigh the disadvantage of increased specific energy consumption.

Research and development needs and goals

Adoption of fuel cells to meet the power requirement of cement manufacture, along with large-scale dissemination of certain futuristic comminution technologies, seems to offer significant energy reduction opportunities. Development of newer types of low-carbon cement (Box 3) could also be a major emissions reduction opportunity. However, these are still only viable at laboratory scale and a major thrust in R&D is required to advance to pilot and demonstration scales, and then to wide spread implementation. Concerted efforts of key stakeholders are essential to stimulate the emergence of such transformational technologies in the global and Indian cement industries in the near future.

Box 3: Potential low-carbon cements

As highlighted in *Cement Technology Roadmap 2009* (IEA/WBCSD, 2009), a number of low-carbon or carbon-negative cements are currently being developed by some companies that expect to build pilot plants in the near future. The physical properties of these cements appear to be similar to those of OPC, and hold equally strong potential for the global and Indian cement industries. These new processes are still at the development stage, but are advancing steadily.

- The **Aether** clinker project aims to develop a new class of lower-carbon clinkers to be used in cement production. The clinker can be made in existing cement plants (after certain process adaptations have been made) with the same raw materials but, crucially, needs less energy. Aether cements are expected to offer similar performances to conventional OPC in various concrete applications, but trials are still underway. During the first industrial trial in February 2011, 5 000 tonnes of Aether clinker was produced, confirming the feasibility of industrial-scale production and the expected 25% to 30% fewer CO_2 emissions per tonne of cement than OPC.
- **Calera**'s key process is the technology associated with carbon capture and conversion to stable solid minerals. This involves bringing gas from the power plant in contact with alkaline water to form soluble carbonates, which then react with hard water to form solid mineral carbonates and bicarbonates. These solid mineral carbonates and bicarbonates now contain CO_2 that would have been emitted into the air. After removal from the water and with further processing, the solids have value in a number of construction applications. However, alone, it does not produce cement or concretes with properties that meet the requirements of cement standards, and is therefore not currently envisaged as a process that would produce a cement-like product for widespread construction use.
- **Calix** cement is produced in a reactor by rapid calcination of dolomitic rock in superheated steam. The particles of rock are dropped into a vertical tube of superheated steam, which causes the particles to explode into grains, increasing the overall surface area. Those grains then react with the steam, oxidising the surfaces, and the residue can be ground into a powder and mixed with sand to form a powder. The CO_2 emissions from this process can be captured using a separate CO_2 scrubbing system.
- **Celitement** is made through a novel production process, the main stage of which requires temperatures of about 200°C, compared to 1 450°C for conventional cement manufacture. Its developers claim that the process emits 50% less CO_2 than OPC manufacturing. The new cement is characterised by a low consumption of resources: approximately one-third of the amount of limestone is required and it can be done completely without a gypsum additive. Celitement GmbH has engineered a pilot plant now in operation to supply sufficient quantities for testing of basic properties and recipes.

Box 3: Potential low-carbon cements (continued)

- **Novacem** is based on magnesium silicates rather than limestone (calcium carbonate) as is used in OPC. Global reserves of magnesium silicates are estimated to be large, but these are not uniformly distributed. Processing would be required before use, for example quarrying and grinding as required for limestone in OPC manufacture. Using a low-carbon, low-temperature process, the technology converts magnesium silicates into magnesium oxide and magnesium carbonate. Production of magnesium carbonate involves CO_2 absorption which, combined with the non-carbonate raw material and the ability to utilise low-carbon fuels, offers the prospect of carbon-negative cement. Makers of Novacem assert that this new cement could be carbon-negative as it has the capacity to absorb 30 $kgCO_2$/t cement to 100 $kgCO_2$/t cement whereas OPC manufacturing leads to emissions of around 800 $kgCO_2$/t cement. Although it had plans to develop pilot and demonstration plants, Novacem is currently seeking additional funding and support to develop and commercialise the product.

In the long term, low-carbon cements may offer opportunities to reduce the CO_2 intensity of cement production. Their progress should be followed carefully and potentially supported by governments and industry.

Table 5: Partner roles (energy efficiency)

Item/ Partner	Cement industry	Equipment suppliers	Government	Universities/ academia	Research institutions	Industry associations
Best practices	✓	✓₹	✓₹		✓	✓
Technology research	✓₹	✓₹	₹	✓	✓	
Technology diffusion	✓₹	✓₹	₹			✓
Institutional structure	✓	✓	✓₹	✓	✓	✓
Performance data	✓		✓		✓	✓

Notes: ✓= leadership role and direct involvement required; ₹ = funding source.

Table 6: Potential impacts (energy efficiency)

Parameter/ Impact	Low	Medium	High
Energy savings			
Carbon savings			
Cement production			
Investment needs			

Technology: clinker substitution

Clinker is the main component in most types of cement. When ground and mixed with 4% to 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 (GBFS, a by-product from the iron and 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, thereby 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 (*i.e.* the "clinker-to-cement" ratio) can vary widely, although the extremes are used only for special applications. OPC can contain up to 95% clinker (the balance being gypsum).

The Indian cement industry has been gradually increasing the share of blended cement in its overall cement mix. The shares of various types of cement and typical average clinker-to-cement ratio for about 200 million tonnes per annum (MTPA) of cement manufactured in India in the financial year 2010 is presented in Table 7.

The potential to reduce the clinker-to-cement ratio depends greatly on the country context and the availability of alternative materials. Under a 2DS, in which the power sector is virtually decarbonised, availability of fly ash would be considerably reduced as a result of fewer coal-based thermal power plants being in operation. However, as the Indian industrial sector is expected to grow at a fast pace, availability of GBFS and other blending material from non-ferrous industries may increase considerably.

Table 7: Share of cement type and typical clinker-to-cement ratio in India

Type of cement	*Million tonnes per annum*	*Clinker-to-cement ratio*
OPC	48	0.95
PPC	130	0.69
PSC	16	0.57
Others	6	n.a.
Total/weighted average	200	0.744

Note: n.a. = not available.

Table 8: Characteristics of clinker substitutes in India

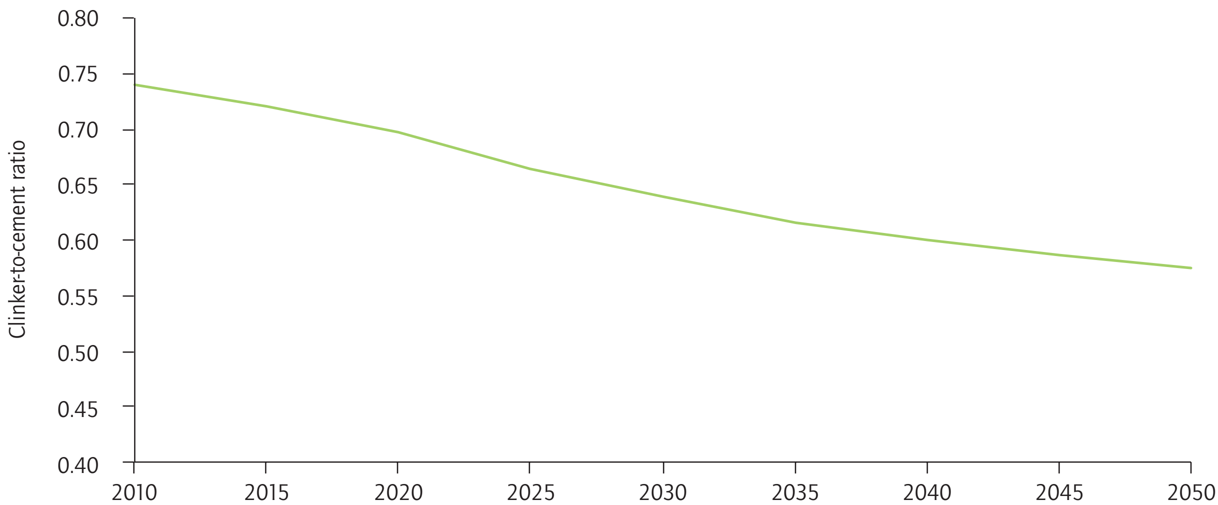
Clinker substitute	*Source*	*Characteristics of the blended product compared to OPC*		*Estimated annual level of availability and use in India*
		Positive	Limiting	2010
Fly ash	Coal-fired power plants	Higher long-term strength, increased durability, lower water consumption, better workability.	Relatively lower early strength, logistic barriers (distance between power plant and cement plant).	100 MTPA of fly ash utilised out of 190 MTPA generated.
Ground blast furnace slag (GBFS)	Iron and steel industry	Improved chemical resistance, higher long-term strength.	Relatively lower early strength, logistic barriers (distance between iron and steel plant and cement plant).	10 MTPA of GBFS utilised out of 22 MTPA of blast furnace slag generated.
Other blending materials	Non-ferrous industries, mineral processing industries	Increased durability.	Relatively lower early strength, presence of minor constituents (*e.g.* magnesium oxide [MgO]), logistic barriers (distance between other industries and cement plant).	Lead zinc slag (1.0 MTPA), copper slag (0.8 MTPA), equilibrium catalyst (0.015 MTPA), Jarosite (0.3 MTPA), Kimberlite (0.6 MTPA), marble slurry (5.0 MTPA).
Limestone	Limestone deposits	Increased workability, higher long-term strength.	None.	Relatively large deposits, but only 40 years of high-grade limestone estimated to be available.

Further analysis on the availability of each material under different scenarios needs to be undertaken to ensure the target set in the roadmap can be achieved. Furthermore, care must be taken to ensure that the resulting new blending will be strong enough for the applications of cement.

Several different clinker substitutes can potentially be used in cement, and their relative merits and availability are presented in Table 8.

The current clinker-to-cement ratio in India is estimated at 0.74, compared to a global average of 0.80. By 2050, this ratio in India is expected to decrease to 0.73 in the 6DS and 0.58 in the 2DS (Figure 8), the latter of which would have a strong impact on the energy consumption and CO_2 emissions. If the clinker-to-cement ratio was the only lever implemented, and all other things remained constant, the savings by 2050 in the 2DS (from the 6DS) would be between 370 PJ and 580 PJ of energy and between 95 $MtCO_2$ and 150 $MtCO_2$ (Low- and High-Demand Case). It is important to note, however, that reductions associated with a lower clinker-to-cement ratio will be impacted by the improvement in thermal energy consumption. In this instance, the combined effect of all levers will be lower than the sum of the individual impacts.

Figure 8: Projected change in clinker-to-cement ratio in the 2DS



Note: Clinker-to-cement ratio is assumed to be the same in the Low- and High-Demand Case.

KEY POINT: The clinker-to-cement ratio will decrease substantially in the next 40 years to reach 0.58.

Challenges to implementation

Some of the major limiting factors in adopting higher clinker substitution rates are the following:

- The Indian standard that limits fly ash addition in PPC (IS 1489) (maximum of 35% by weight for siliceous fly ash) as compared to European standards (permits up to 55%).
- A lack of economically viable and proven technologies for utilising huge deposits of pond/dump ash.
- Absence of standards for composite cement and Portland Limestone Cement (PLC); inadequate infrastructure to granulate all blast furnace slag generated.
- Lack of strong co-operation between the cement and steel industries, specifically on joint efforts to activate non-granulated blast furnace slag and to produce granulated slag economically. Quantity and quality variation of dolomite and other blending materials.
- Lack of systematic and thorough studies/investigations to prove extent of clinker substitution.
- Long distance between source of blending materials and cement plants and logistics (*e.g.* rail connectivity) are major barriers to increased and effective use of all blending materials and are affecting economic viability of the usage.

Research and development needs and goals

Variation in the quality is one of the major problems hindering widespread use of fly ash. Efficient coal blending systems and controlled coal combustion techniques will ensure the generation of good quality fly ash in Indian thermal power plants. Studies are required, however, to find ways to enhance lime reactivity of dump ash/pond ash and fly ash from electrostatic precipitators so that non-conforming fly ash could be made reactive and could conform to the Indian standard for fly ash utilisation.

Economically viable technologies for activation of non-granulated blast furnace slag are not available at present. It may not be possible to increase availability of such slag in the very near term, but activation processes (such as fine-grinding using nanotechnology and re-sintering and quenching) could be possible through adequate research and deployment in industry.

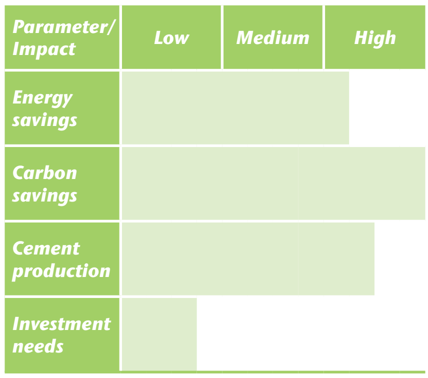
The lack of reliable basic data on cement blend characteristics (of blending materials from non-ferrous and mineral processing industries) and their performance in the Indian context, highlights the need for further research to prove their viability and substitution in cement.

Table 9: Partner roles (clinker substitutes)

Item/ Partner	*Cement industry*	*Equipment suppliers*	*Government*	*Universities/ academia*	*Research institutions*	*Industry associations*	*Standardisation organisations*
Best practices	✓	✓			✓	✓	✓
Technology research	✓₹	✓	₹	✓	✓		✓
Technology diffusion	✓₹	✓	₹			✓	✓
Institutional structure	✓	✓	✓	✓	✓	✓	✓
Performance data	✓			✓	✓	✓	✓

Notes: ✓= leadership role and direct involvement required; ₹ = funding source.

Table 10: Potential impacts (clinker substitutes)



Technology: waste heat recovery

Adoption of WHR systems in Indian cement manufacturing facilities has been relatively slow compared to in other countries. Out of about 183 large cement kilns in the country, only 12 have WHR systems installed. The WHR potential of the Indian cement industry is estimated at close to 550 MW while the installed capacity to date is only 110 MW. Clearly, a huge opportunity exists for adopting WHR.

While Indian cement manufacturers accept the technology of WHR systems, the main reasons for low adoption have been layout constraints, high capital costs for smaller capacity plants, lack of uniform policy across all states regarding the renewable status for WHR systems, and lack of attractive financial incentives to enable implementation.

The high initial investment deters manufacturers from adopting WHR systems. Installing WHR systems currently costs manufacturers about USD 2.4 million (INR 12 crore) per MW, depending on the type of technology adopted and the WHR potential at each plant. By contrast, about 60% of the electrical energy requirements for cement manufacture in India are met through CPP (installed to reduce cost of energy and to ensure steady power availability). Installing CPPs cost cement manufacturers about USD 1 million (INR 5 crore) per MW.

Based on the chosen process and kiln technology, 7 kWh/t to 10 kWh/t clinker can be produced from cooler exhaust air and 8 kWh/t to 10 kWh/t clinker from preheater gases, if the moisture content in the raw material is low and so requires only little hot gas/air for drying. This means that, in total, up to 15 kWh/t to 20 kWh/t clinker or up to 12% to 15% of the power consumption of a cement plant can be generated by using currently available WHR technologies without significant changes in kiln operation. The plants can either reduce their power requirements or export the power to the grid.

Overall, between 5 000 GWh (Low-Demand Case) and 10 000 GWh (High-Demand Case) of electricity could be saved by 2050 by installing WHR in new and refurbished cement plants.

Challenges to implementation

The feasibility of implementing WHR systems in cement manufacturing facilities is limited largely by the moisture content in the raw material. In facilities where the raw material moisture levels exceed 8%, WHR systems are not viable as the hot gases recovered are required for drying.

In facilities where raw material drying is feasible, economic viability is the parameter that limits implementation. Poor payback on investments, lack of financial incentives and the relatively low cost of captive power (wherever CPPs are already installed for power requirements) hinder widespread adoption of WHR systems. Less weighty but still important factors include the type of cooler used, space and layout considerations at the plant, dust concentration levels, availability of water and scale of operation of manufacturing facilities.

Research and development needs and goals

Some existing cement plant installations in India have adopted conventional or organic rankine cycle systems. Power generation from WHR systems depends largely on the type of system adopted. Research into maximising power generation from already-proven WHR systems (through recovery of radiation losses in the kiln system) will help make the economics of implementation attractive.

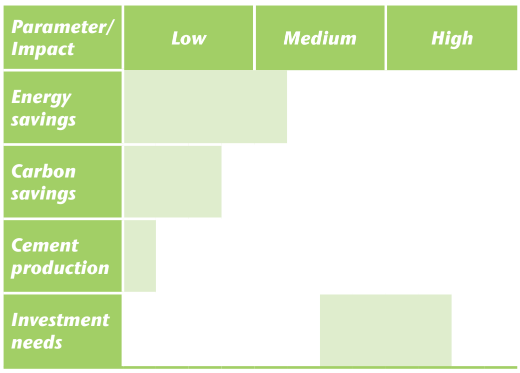
Newer WHR technologies, such as the Kalina cycle, are yet to be adopted in India. R&D is essential to promote increased use of this technology, which offers higher power generation possibility compared to other cycles. Lower investment costs could also stimulate adoption.

Table 11: Partner roles (WHR)

Item/ Partner	Cement industry	Equipment suppliers	Government	Universities/ academia	Research institutions	Industry associations
Best practices	✓	✓				✓
Technology research	✓₹	✓₹	₹	✓	✓	
Technology diffusion	✓	✓	₹			✓
Institutional structure	✓	✓	✓	✓	✓	✓
Performance data	✓					✓

Notes: ✓= leadership role and direct involvement required; ₹ = funding source.

Table 12: Potential impacts (WHR)



Technology: newer technologies

Several newer technologies that could significantly improve the CO_2 emissions reduction profile of the Indian cement industry are at various stages of development: use of mineralisers, fluidised-bed advanced cement kiln system (FAKS), carbon capture and carbon use for algal growth for biofuels production, geopolymer cement and use of nanotechnology in cement production.

Use of mineralisers to improve burnability of the raw mix

Mineralisers added to raw materials entering the kiln can reduce the clinkerisation temperature by about 50°C (or more) without compromising clinker quality, thereby reducing fuel consumption and emissions while also improving the clinker morphology. The selection and use of the mineralisers is generally determined by considerations such as the reaction effects desired, compatibility with a given kiln's raw materials, the specific process adopted, physical form of the mineralisers and economic viability of using mineralisers.

Fluidised-bed advanced cement kiln system (FAKS)

The fluidised bed, which is widely used in some other industries, shows promise to improve thermal efficiency in cement production, although its suitability at scale is yet to be proven. With no other breakthrough technologies envisaged to deliver significantly higher thermal or electric efficiency, it is vital to ensure that new plants are fitted with the most efficient technologies, and are then operated and maintained well. Granulation control technology is the most important component in the FAKS system. It offers the first "self-granulation" process, whereby agglomeration of a portion of the raw material generates granule cores to which the remaining raw material adheres and "grows", thereby controlling granulation.

Algal growth promotion and use of biofuels

Algae can be used either directly as a fuel or by converting it to biofuels to provide energy for cement production. Algal growth can be promoted by raising CO_2 levels in the growing environment; the necessary photosynthesis can be stimulated in either open ponds or closed bioreactor systems in the presence of light. As open pond systems have been deemed commercially unviable, researchers have designed different bioreactors with varying efficiencies. The CO_2 needed could be provided either directly from the kiln flue gases or in a more pure form via a CO_2 capture plant. Using this biofuel to displace fossil fuels would deliver an associated emissions benefit elsewhere in the value chain.

Geopolymer cement

Geopolymer cements are two component binders consisting of a reactive solid component and an alkaline activator. During the reaction in alkaline media, a three-dimensional inorganic aluminosilicate polymer network forms, which is responsible for the relatively high strength of the hardened product. Geopolymer cements are already in use but not widely.

Use of nanotechnology in cement production

Nano-cements are cements containing nano-sized particles of cement evenly distributed among larger particles of mineral admixtures. The nano-particles are dispersed so finely that even a lower content of cement should be able to provide the desired binding of aggregates and admixture particles, generating the required strength and performance in the final concrete. Nano-cement production allows for the use of larger quantities of mineral additives, and therefore have the potential to provide significant savings of cement and lower CO_2 emissions.

Nano-particles can also support mechano-chemical activation of raw materials and cements, which may provide enhanced reactivity during clinkerisation (for raw materials) and hydration (for cement). The most studied and well-reported area is the use of nano-particles, such as nano-silica, in cement mortar and concrete.

Potential health hazards associated with the handling and use of nano-particles need to be studied, understood and mitigated.

Carbon capture and storage (CCS)

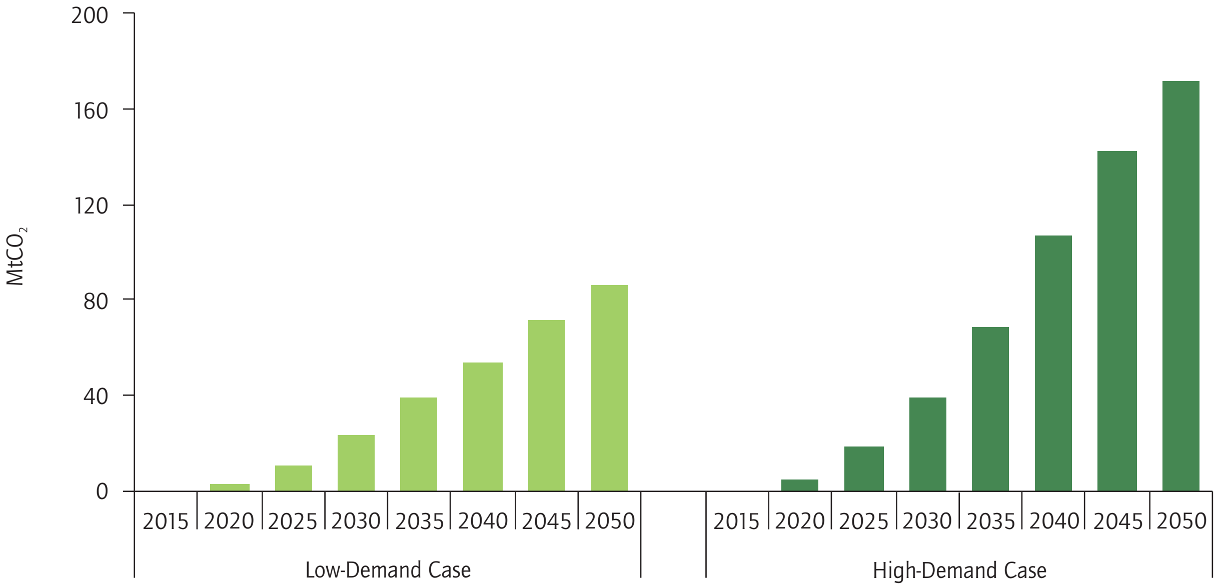
Among the newer technologies for CO_2 emissions reduction presented in this roadmap, only CCS is considered to become commercially available over the timeframe analysed. CO_2 capture through post- and oxy-combustion in the cement industry is currently at the pilot stage. If pilot testing is successful, and actions are quickly taken to overcome the barriers to CCS, it could contribute between 86 $MtCO_2$ and 171 $MtCO_2$ of the emissions reduction from the Indian cement industry by 2050. 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 at conceptual design stage.

Several barriers still need to be overcome before CCS can be commercially applied in the cement sector. Post-combustion technologies – end-of-pipe mechanisms – will not require fundamental changes in the clinker-burning process, and could be retrofitted to existing plants depending on space restrictions. However, the energy requirements for the regeneration of the capture solvents used in post-combustion capture may require additional boilers on site or off-take of steam from a local power plant.

Oxy-combustion, which involves the use of an oxygen-enriched combustion environment to produce a pure CO_2 flue gas, has been shown to improve cement production efficiency without markedly increasing the fuel consumption of a cement plant.

Oxy-combustion technologies have their own disadvantages, however. While they can avoid the high energy costs associated with all post-combustion capture techniques, the cost of oxygen

Figure 9: Potential growth of CCS in the Indian cement industry in the 2DS



KEY POINT: CCS could be a key option to reduce CO_2 emissions from the cement industry.

gas production is high. Moreover, significant re-engineering of the plant may be needed to accommodate altered thermodynamics and material stress of operation in an oxygen-rich environment. Concerted R&D into oxy-combustion is warranted to better understand any impacts on product quality.

Challenges to implementation

At present, none of these newer technologies are commercially established. While all have significant emissions reduction potential, their commercial viability and successful deployment is key to increased adoption.

Research and development needs and goals

Primary and fundamental research is needed in areas such as nano-technology and geopolymer cement. For fuel cells or use of mineralisers, future development hinges more on achieving commercial viability. In all cases, carrying out R&D within India is essential to ensuring country-specific, cost-effective and technically viable options for emissions reduction.

Table 13: Partner roles (newer technologies)

Item/ Partner	Cement industry	Equipment suppliers	Government	Universities/ academia	Research institutions	Industry associations
Best practices	✓	✓			✓	✓
Technology research	✓₹	✓₹	₹	✓	✓	
Technology diffusion	✓	✓	₹		✓	✓
Institutional structure	✓	✓	✓	✓	✓	✓
Performance data	✓				✓	✓

Notes: ✓= leadership role and direct involvement required; ₹ = funding source.

Table 14: Potential impacts (newer technologies)

Parameter/ Impact	Low	Medium	High
Energy savings			
Carbon savings			
Cement production			
Investment needs			

Reduction potential from captive power generation

Somewhat uniquely to India, CPPs have become an integral part of the cement manufacturing process. In fact, the electrical power requirement for around 60% of the cement manufactured in India is met through CPPs (predominantly coal-fired) installed at cement manufacturing facilities. Efficiency improvements and use of renewable energy in CPPs are essential to support the Indian cement industry's endeavour to move towards a low-carbon economy.

The opportunities for efficiency improvements in the cement manufacturing process are discussed at length in the roadmap as well as in the accompanying technical papers. The roadmap limits discussion of emissions reduction levers to those specific to the cement manufacturing process, and so reduction potential from captive power generation is not considered as an emissions reduction lever in this roadmap. However, there is important emissions reduction potential associated with energy efficient CPP and the use of alternative fuels to generate power. Captive power generation has the potential to improve energy security of the country by reducing the electricity required for cement manufacturing from public utilities.

The estimated average auxiliary power consumption in cement industry CPPs ranges from 10% to 13%. Some of the best operating CPPs in the Indian cement industry operate at 5% of auxiliary power consumption. A similar range is also observed in the CPP heat rate: the average heat rate of all CPPs installed in the Indian cement industry is 3 208 kcal/kWh (source: Bureau of Energy Efficiency for baseline period 2007-10) as compared to 2 550 kcal/kWh in best operating plants.

About 60% of the electricity used in cement plants today is from CPPs, which have an average CO_2 emission factor of 1.2 $kgCO_2$/kWh of electricity produced. Improved energy efficiency, coupled with power generation through low (or zero) emission technologies, can substantially reduce CO_2 emissions from CPPs. Assuming that CPPs will continue to account for around 60% of cement electricity requirements in 2050, between 80 $MtCO_2$ and 150 $MtCO_2$ could be saved through efficiency improvements and the use of renewable energy to generate 50% of the electricity needs.

Energy efficiency

Energy efficient captive power generation can be achieved in two ways: energy efficiency by design when building new plants, and energy efficiency by retrofitting existing CPPs with more efficient technologies. Significant efficiency improvements can be achieved through various means including the choice of fluidised-bed boilers by design for better efficiency (for example, circulating fluidised-bed combustion [CFBC] system in lieu of atmospheric fluidised-bed combustion [AFBC] system), and efficiency improvements in existing auxiliary equipment (such as feed water pumps, fans, compressors, cooling towers and installation of variable speed drives for all auxiliary equipment).

Renewable energy

Government of India targets are to achieve over 20% of the country's total power generation from renewable energy (RE) by 2022, with an installed capacity of over 70 GW (MNRE, 2011). To support this aim, the government recently launched two national missions: the 2010 Jawaharlal Nehru National Solar Mission under the NAPCC seeks to facilitate the generation of 20 000 MW of solar power by 2022. The recently initiated National Biomass Mission aims to tap bioenergy potential of over 25 000 MW. Various RE-based power generation options are available for cement manufacturers to supplement their fossil fuel-based electricity supply including wind power, biomass-based power generation, solar photovoltaic (PV), solar thermal and small hydropower generation.

Fuel cell technology

After a few successful commercial installations at various capacities, hydrogen fuel cell power may become a clean power generation technology in the future. Currently, fuel cell technology in a small capacity is undergoing commercial trials in different parts of the world. In these trials, technology suppliers are willing to supply the power with a power purchase agreement at a price comparable to prevailing conventional power cost. Typically, a 50 MW plant requires ten acres (1 acre = 4 047 square metres) of land and an initial provision of approximately 50 000 litres of fresh water. The water can be recycled, which means that only evaporation and drip losses need to be replenished (estimated at approximately 7% to 8%).

Challenges to implementation

Installation of CPP will continue to expand so long as India remains unable to supply steady and continuous grid power at a competitive cost (compared to captive generation). All the options discussed for energy efficiency improvements in existing CPPs are proven and can be considered for direct implementation. Low-carbon power generation options, such as renewable energy and/or fuel cells, would achieve greater penetration if cost economics justify their use.

Research and development needs and goals

While much effort targets performance improvements at large thermal power plants, very little work is being done on energy efficiency improvements in CPPs. Research and development needs are required in efficiency improvements of existing thermal-based CPPs as well as developing RE systems that can be integrated into cement manufacturing process/requirements.

Table 15: Partner roles (CPP)

Item/ Partner	Cement industry	Equipment suppliers	Government	Universities/ academia	Research institutions	Industry associations
Best practices	✓₹			✓	✓	✓
Technology research		✓₹	₹	✓		✓
Technology diffusion			₹		✓	✓
Institutional structure			✓₹			✓
Performance data	✓₹	✓₹			✓	✓

Notes: ✓= leadership role and direct involvement required; ₹ = funding source.

Table 16: Potential impacts (CPP)

What policy support is needed?

Successful achievement of the energy efficiency improvements and emissions reduction goals outlined in this roadmap will require a well-designed and supportive policy framework. This roadmap proposes policy recommendations to stimulate the necessary technology development and deployment.

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. Globally, industry has a good understanding of the processes for using AFRs and potential for increased implementation. India, however, still lacks appropriate legislative and regulatory frameworks to support roll-out and/or expansion of this practice. If policy is supportive of increased AFR use, estimates propose that average thermal substitution rates in India could be 19% in 2030, and 25% in 2050, compared to 0.6% today.

Current barriers to wider alternative fuel use include: variations in availability of alternative fuels and biomass due to weak legislation around waste collection, segregation and processing; lack of acceptance of co-processing as a viable waste disposal method for municipal and industrial wastes; existing legislation related to inter-state transportation of alternative fuels; poor public understanding and acceptance; and unviable pricing of alternative wastes available to the cement industry.

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 EU document *The Reference Document on Best Available Techniques in the Cement, Lime and Magnesium Oxide Manufacturing Industries* (EU, 2010).

Political commitment to enhancing renewable energy use in India started in the 1970s, and is now driven by the Ministry of New and Renewable Energy (MNRE). In addition to supporting R&D, the Ministry facilitates the implementation of broad spectrum programmes including the use of renewable energy in urban, industrial and commercial applications and the development of alternate fuels and applications. MNRE has set up centres of excellence for solar and wind energy, as well as a separate financing institution, the Indian Renewable Energy Development Agency (IREDA).

MNRE also led the development of the Renewable Purchase Obligation (RPO), which will support the Government of India's aim to derive 15% of energy requirements from renewable energy by 2020. Under the RPO, distribution companies, open-access consumers and captive consumers are obliged to buy a specific percentage of their power from RE sources.

To encourage and facilitate increased alternative fuel use, this roadmap recommends:

- Developing legislation on waste management at national, state and local levels, to promote co-processing as the preferred choice of waste disposal if landfill is the only other option, and as an integral part of India's future waste management strategy at all levels.
- Working with NGOs to improve social acceptance of using wastes as AFR in cement kilns through appropriate awareness and governing mechanisms so all stakeholders understand the role of AFR use in emissions reduction and in India's waste management practices.
- Waste generators and the cement industry should ensure effective collaboration and oversight of the collection, segregation, transportation and processing of waste in a manner acceptable to the cement industry for both quality and cost.
- Establishing common guidelines for operators on AFR use to guarantee adequate processes, for example induction and retraining, documenting and monitoring, for employees and contractors, and to ensure adherence to these guidelines; provide training for authorities and ensure an adequate technical background of decision makers responsible for permits, control and supervision.
- Establishing legislation to support inter-state transport of correctly managed hazardous waste, thereby facilitating movement of such wastes between states that have high waste volumes and those with strong cement industry presence.
- Establishing an appropriate pricing scheme of alternative fuels to encourage cement manufacturers to install the (expensive) handling, storage and firing facilities at their plants.
- Conducting detailed analysis of current and future availability of varied alternative fuels in partnership with local authorities (municipal solid waste) and other industries (industrial waste).
- Ensuring that no taxes are levied on co-processing for environmentally safe disposal of industrial or municipal waste.

Box 4: India's Perform, Achieve and Trade (PAT) scheme

The Ministry of Power's Bureau of Energy Efficiency (BEE) has been a leader in promoting the efficient use of energy and its conservation. This is further supplemented by the National Mission for Enhanced Energy Efficiency (NMEEE) which is one of the missions of the NAPCC, released on 30 June 2008 to ensure an increase in the living standards of the vast majority of people while addressing greenhouse-gas mitigation and reducing vulnerability to adverse impacts of climate change. The flagship program of the NMEEE, the Perform, Achieve and Trade (PAT) mechanism, seeks to create, in the words of the NAPCC, a market-based mechanism to facilitate energy efficiency improvements in large energy-intensive industries through trading of certified energy savings.

The key goal of the scheme is to mandate specific energy efficiency for the most energy-intensive industries, and further incentivise them to achieve better energy efficiency improvements that are superior to their specified specific energy consumption improvement targets. To facilitate this, the scheme provides the option to industries which achieve superior savings to receive energy savings certificates for these excess savings, and to trade the additional energy savings certificates with other energy-intensive industries (the Designated Consumers [DC]), who can utilise these certificates to comply with their own reduction targets. The Energy Savings Certificates (ESCerts) so issued will be tradable on special trading platforms to be created in the two power exchanges (Indian Energy Exchange and Power Exchange India).

BEE conducted several studies before starting the procedure of target setting in different industries. Each DC is mandated to reduce its specific energy consumption by a certain value. This value is based on the reported specific energy consumption of each individual plant within the sectoral bandwidth. The plants that are already efficient have a lower mandated reduction than those that are less efficient.

The cement plant is an energy-intensive unit, where the energy cost accounts for about 40% of the total manufacturing cost. The specific thermal and electrical energy consumption for state-of-the-art cement plants is comparable with the best plants in the world. The most efficient global technologies have been adopted in the major Indian cement plants which are already leaders in the field of energy conservation. Energy savings of 0.816 million tonnes of oil equivalent (Mtoe) (34 PJ) per year are expected to be achieved, which is around 12% of total national energy saving targets assessed under PAT.

Source: BEE, Background on PAT, October 2012.

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

Widespread implementation of dry process kilns with preheaters and precalciners has allowed the Indian cement industry to significantly reduce its energy and emissions intensity. Moreover, new cement kilns in India are among the most efficient in the world. In many cases, companies have opted for best available technologies at the time of construction, and older plants are refurbished to high efficiency levels.

Nevertheless, further improvements in energy efficiency are still possible, and these bring cost savings to the plant as well as decreasing the risks of disruptions in energy supplies. India's NMEEE has a set of market interventions, covering the major economic sectors, to achieve energy efficiency targets of reducing energy intensity by 20%. BEE has created funds available to varied industry sectors including cement, like the Partial Risk Guarantee Fund for Energy Efficiency (PRGFEE) or the Venture Capital Fund for Energy Efficiency (VCFEE), to overcome risks that impede the implementation of energy efficiency technologies. Strong enforcement of increasingly stringent environmental norms across the industry will increase specific energy consumption and necessitate the installation of energy efficient equipment to reduce the specific energy requirements and maintain cost competitiveness.

To promote the adoption of BATs for new and retrofit kilns, this roadmap recommends:

- Effective implementation of the PAT scheme and its continuation in subsequent cycles.
- Eliminating energy price subsidies that can act as a barrier to implementation of more energy efficient technologies.
- Sharing of best practices and implementing policies for the promotion of energy efficiency and CO_2 emissions reduction in the cement industry.
- Defining minimum ESCerts price in a similar way to the Renewable Energy Certificate (REC) trading mechanism, which will encourage companies to implement high capital expenditure (CAPEX) and long payback projects.
- Strengthening co-operation to gather reliable, industry-level energy and emissions data, for example linking to the CSI's GNR database; supporting effective policy development; tracking performance; and identifying national performance gaps and best practice benchmarks.

Encourage and facilitate increased clinker substitution

In India, the estimated generation of fly ash was about 190 Mt in 2010/11; this is expected to reach 450 Mt by 2020/21, and 900 Mt by 2031/32 (Department of Science and Technology, Government of India). At present, only about 100 Mt of fly ash is being used in cement and other building materials. Current factors that impede the full potential of clinker substitution include: existing cement standards (or lack of) and building codes; poor understanding of the process by the public and customers; and lack of availability (both locally and regionally) of substitute materials.

To encourage and facilitate increased clinker substitution, this roadmap recommends:

- Conducting detailed analysis of current and future availability of clinker substitutes.
- Revising existing cement standards and building codes to allow the use of a higher percentage of fly ash in blended cement.
- Developing new cement standards and building codes to promote widespread use of blended cement, for example developing a standard specification for composite cement and PLC or for using industrial waste from the non-ferrous industries as clinker substitutes.
- Raising consumer awareness and confidence in blended cements and increasing their acceptance in the market.
- Promoting capacity-building and training events with standardisation bodies and accreditation institutes to exchange experiences on substitution, concrete standards, long-term concrete performance of new cements, and environmental and economic impacts; ensuring consumers are trained in using blended cement.
- Ensuring the availability of clinker substitutes for the cement industry to conserve limestone reserves and minimise CO_2 emissions from cement manufacturing.

Facilitate the development of CCS and biofuels production and use by the cement industry

From among the newer technology options, carbon capture and storage is a technology not yet proven at industrial scale in cement production, but which could potentially deliver deep cuts in CO_2 emissions within the global cement industry; thus, urgent action is needed to support its development. Research and development, pilot projects and industrial-scale demonstration on effective CO_2 capture in the cement industry must be incentivised and put into action in the short term to enable full-scale capture for decades to come. Demonstration and deployment of CO_2 capture technologies will support the full CCS chain.

The marginal abatement cost of CCS at the global level is estimated at USD 40/tCO_2 abated to USD 170/tCO_2 abated (INR 2 200/tCO_2 to INR 8 500/tCO_2) (IEA, 2009). At this cost, its implementation would require significant capital and could result in a doubling of cement production costs which cannot be burdened on the end consumer alone. In the absence of a global framework, implementation of CCS technology will be possible only if national and regional political frameworks effectively limit the risk of carbon leakage. As the additional cost of CCS implementation will be lower for new installations than for retrofitting existing facilities, and as the majority of future demand is likely to be in regions that currently have lower carbon constraints, incentives must be in place to encourage the early deployment of CCS in all regions. To date, no cement plant has demonstrated CCS at a commercial scale. Therefore deployment of CCS in the cement industry now depends on establishing techno-commercial viability of CCS and understanding the resulting impact on production cost. In India, the cement industry has made several attempts to recover CO_2 from the flue gas using physical and chemical methods.

CO_2 could also potentially be removed from cement kiln flue gases through the industrial-scale photosynthesis of algae in photobioreactors. This would not lead to capture or storage of the CO_2; rather, the algae would be used to generate biofuel that would replace fossil fuel, thus displacing emissions associated with fuel use. Use of biofuels is likely to lead to a reduction in overall carbon intensity. The direct CO_2 reduction potential depends on the type, volume, technology and conditions of the algae, and on the fuel displaced.

To facilitate the development of CCS and biofuel production and use, this roadmap recommends:

- Promoting, piloting and commercialising CO_2 use for algae growth at Indian cement plants.
- If CO_2 reductions to reach the 2DS are not possible through CO_2 use for algal growth, governments need to consider alternatives including CO_2 capture (with international funding support).
- Developing knowledge of potential geological CO_2 storage sites in India; mapping a CO_2 storage atlas (sponsored by government).
- Identifying industrial sites that could cluster the captured emissions from cement plants with those of other industries. This would reduce costs and help to commercialise CCS under a policy framework that attracts international funding support.
- Government and industry significantly expanding efforts to educate and inform key stakeholders about CCS.
- If technically suitable and safe geological structure to store CO_2 are available, Government of India to develop CO_2 transport networks on a regional, national and international level to optimise infrastructure development and to lower cost of CCS.

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

Until there is clarity internationally on the future carbon constraints that will be imposed upon countries and industrial sectors, it is difficult for industry around the world to plan effectively for technology R&D. Carbon pricing policies (such as emissions trading, either domestically or internationally) can help bridge the cost gap and drive deployment of mature lower emission technologies. However, carbon markets must be complemented by mechanisms that effectively engage all industries in developing and adopting cleaner technologies for emissions reduction.

International climate change negotiations are beginning to shape the future agreement that will apply from 2020. This agreement foresees new market mechanisms that would stimulate emissions reduction across broad segments of economies, rather than by funding individual projects. Developed countries have committed to mobilise significant financial flows for low-carbon investment in developing countries, including helping fund nationally appropriate mitigation actions (NAMAs) put forward by developing countries. This new international agreement may have scope for ambitious mitigation efforts in the Indian cement industry, to be supported by new market mechanisms or directly by mobilised financial flows.

To encourage policies for CO_2 constraints and energy frameworks, this roadmap recommends:

- Government-industry collaboration to inform the United Nations Framework Convention on Climate Change (UNFCCC) process, specifically to explore key elements for successful frameworks: *e.g.* sector data requirements; monitoring, reporting and verification (MRV) practices; target setting; and potential market (crediting or trading) mechanisms based on a common calculation method for CO_2 emissions as stipulated by an international standard.
- Government, in collaboration with industry, 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 co-ordination with trade associations.

- Promoting NAMAs, as a set of country-driven activities leading to measureable, reportable and verifiable greenhouse-gas emissions reduction, and involvement of the cement industry.
- Rewarding clean energy investments, for example fiscal incentives for WHR, and penalising poor energy investments, for example reducing subsidies if energy generation is inefficient.
- Related to CCS in geological formations, supporting the implementation of Clean Development Mechanism (CDM) projects by ensuring that the global political framework effectively limits the risk of carbon leakage and establishing necessary laws or regulations at national level.

Enhance research and development capabilities, skills, expertise and innovation

A significant increase in R&D over the short and very long term is needed in the cement industry in India, as well as globally. Investment along the entire chain of innovation, from college-level training to industrial-scale innovation, must come from academia, industry, equipment suppliers and government. For example, a new generation of hydraulic binders could provide high emissions reduction, but this technology is not yet well understood or developed at scale, and needs further R&D.

New areas of research must be funded and expanded, for example around advanced comminution technologies such as aeroacoustics, ultrasonic comminution, the application of microwave energy to improve comminution efficiency, and electroacoustical comminution processes. These are still in the conceptual/pilot plant stage and not yet commercialised. Nano-cements being developed contain nano-sized particles of cement and mineral admixtures. Research efforts focus on various fields including: the improvement of cement and concrete performance by incorporating nano-particles; and the use of nano-particles to reinforce cementitious materials for improved flexibility and toughness.

At present, there are no policy barriers to the use of nano-particles in cement manufacturing; the policy framework must, however, be well considered if this technology is commercialised. This can only happen if the high costs of nano-particle production are brought down and after health hazards associated with handling and use of nano-particles are studied.

To encourage the development of capabilities, skills, expertise and innovation in the cement industry, this roadmap recommends:

- Increasing the number and skills level of scientific researchers with cement industry expertise, through joint support from industry and government for appropriate university programmes and by creating teaching and research positions on materials science and climate protection by industry.
- Integrating or aligning research programmes at national and international levels, and directly involving companies in programmes.
- Encouraging joint scientific and engineering research projects among countries, and establishing collaborative research programmes or networks among 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 (*e.g.* hydraulic binders) to foster fast uptake of cements with high potential for reducing emissions.

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 reduction technology. International collaboration can catalyse and accelerate technological progress in the demonstration phase. In particular, the installation of critical CCS facilities by 2020 exceeds the financial and technical capacity of individual companies or countries, and so requires large-scale co-operation at all stages.

New forms of public-private partnerships (PPP) 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 relevant example from the steel industry is the Ultra-Low CO_2 Steelmaking (ULCOS) project, in which a consortium of 48 European companies and organisations, financially supported by the European Commission, are undertaking co-operative R&D into CO_2 emissions reduction from steel production.

To encourage international co-operation and public-private partnerships, this roadmap recommends:

- Creating partnerships that help minimise technological risks and create options to increase energy efficiency or reduce CO_2 emissions, for example the GTZ-Holcim PPP co-ordinated by the University of Applied Sciences, Northwestern Switzerland (www.coprocem.org).
- Ensuring international collaboration to potentially lead to CCS demonstration plants in the cement industry.
- Shifting national innovation priorities to ensure that international collaboration on R&D activities around climate protection are 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.

Investment needs, financial support and recommendations

The IEA estimates that the investments needed to meet the increased cement demand in India will range from an estimated USD 118 billion to USD 276 billion (INR 590 000 crore to INR 1 380 000 crore) for the period 2010-50.

The maximum implementation of energy-reducing and low-carbon technologies to meet the reductions envisage under the 2DS would require additional investments of between USD 29 billion and USD 50 billion (INR 145 000 crore to INR 250 000 crore) over the same period, or 15% to 25% higher than in the 6DS. The additional investments would be required to cover the higher costs of more efficient cement kilns, increased use of AFR and clinker substitutes and installation of carbon capture technologies. As the growth in cement demand is expected to peak in 2025-30 in India, investment needs are also estimated to reach a peak in those years, at USD 20 billion to USD 46 billion (INR 100 000 crore to INR 230 000 crore) in the 6DS and USD 22 billion to USD 51 billion (INR 110 000 crore to INR 255 000 crore) in the 2DS.[14]

14. Assumptions used in this roadmap to estimate investments in the cement industry are presented in Annex D.

Table 17: Cumulative investment needs in the Indian cement industry, 2010-50

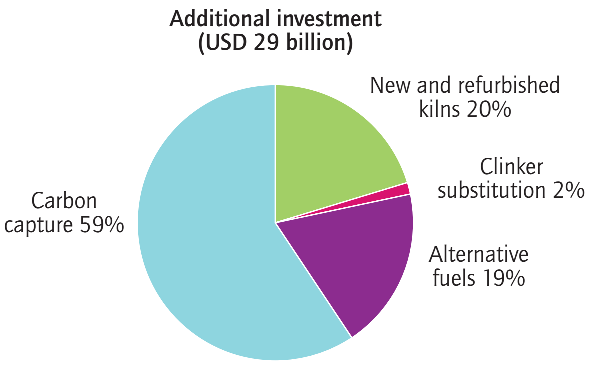
USD billion	6DS		2DS	
	Low-Demand Case	High-Demand Case	Low-Demand Case	High-Demand Case
New and refurbished kilns	117 to 144	222 to 273	123 to 150	222 to 274
Clinker substitution	1.1 to 1.4	2.3 to 2.9	1.6 to 2.0	2.7 to 3.4
Alternative fuels	0	0	5.6 to 5.9	12 to 13
Carbon capture	0	0	17 to 19	33 to 36
Total	**118 to 145**	**224 to 276**	**147 to 177**	**270 to 326**

Notes: Investments for alternative fuels relates to onsite investment to store, load and feed kilns with AFR, and eventually the change of burners and/or emission abatement systems. Investments in carbon capture do not include the cost of transportation and the eventual use or permanent storage of carbon.

In the High-Demand Case, the share of additional investment requirements for more efficient cement kilns rises significantly, in line with the expected production growth in this scenario. This highlights the importance of improved efficiency in lowering energy needs and emissions in the sector. However, the savings from a lower clinker-to-cement ratio in the 2DS (0.73 in the 6DS and 0.58 in the 2DS), and the resulting smaller number of plants required to produce the clinker, will offset the increased investments associated with highly efficient kilns. As a result, investments in the 2DS might be lower than in the 6DS. Overcoming financial barriers related to widespread technology implementation will be important.

In a scenario where private industry has a choice either to increase output or to opt for low-carbon measures, a combination of market mechanisms and regulations is likely needed to ensure that investments do flow to low-carbon measures.

Figure 10: Additional investment needs in the Indian cement industry, Low-Demand Case, 2010-50



***KEY POINT:** About half the additional investments for a low-carbon growth pathway in the Indian cement industry would be required for the application of carbon capture.*

More than 50% of the additional investments will be required for carbon capture. CCS development and demonstration will require support from the international community as the domestic industry cannot bear these costs alone. Post-combustion capture technology could double the investment needs of a cement plant. Traditional financing criteria used by industry are not appropriate for CCS unless a global carbon price (or incentive) is sufficiently high to correctly value the cost of mitigating CO_2 emissions. Unlike energy efficiency technologies that show a return on investment through reduced fuels costs, carbon capture technologies result in higher operating costs. Funding for CCS demonstration in cement is urgently needed.

To encourage investment and financial support, this roadmap recommends:

- New mechanisms emerging from the climate negotiations, such as new market mechanisms and climate finance, combined with India's PAT scheme ESCerts or REC scheme could allow for financing of CO_2 reduction options in the cement industry. The industry should be actively engaged in the development of international mechanisms to ensure the creation of a viable funding path for low-carbon investment.
- Low-cost financing or blended financing (a blend of commercial and concessional finance) to make low-carbon initiatives financially viable, including mechanisms to support higher costs of retrofits.
- Raising awareness in India of existing funding mechanisms; for example, the World Bank's energy efficiency funds, IFC blended financing options, and BEE's energy efficiency incentivisation schemes.
- Continuing and improving of the CDM to simplify procedures and reduce transaction costs, thereby facilitating the funding of energy efficiency, alternative fuel use, clinker substitution projects, and the adoption of CCS in the cement industry.
- Allocating of international and national funding sources for the demonstration of a CO_2 capture project.
- Funding of research institutes to advance demonstration projects for algal growth.

Roadmap action plan

Stakeholders	Action item
All stakeholders	• Intensify collaboration to drive implementation of best available technology across all cement plants in India. • Intensify experience-sharing and knowledge transfer among industry in India and globally.
Ministry of Commerce and Industry (incl. Department of Industrial Policy and Promotion)	• Ensure attractive financial incentives to enable widespread use of blended cement. • Allocate good quality linkage coal to the cement industry to maximize the life of Indian limestone deposits.
Ministry of Consumer Affairs, Food & Public Distribution (incl. Bureau of Indian Standards)	• Develop standards and implement regulation for composite cement and Portland Limestone Cement. • Develop standards and implement regulation for clinker substitutes.
Ministry of Environment and Forests (incl. Central and State Pollution Control Boards)	• Implement appropriate policies and practices in favour of increased AFR use in India. • Ensure that legislation on waste management in India enables effective waste collection, treatment and processing. • Identify and classify suitable materials that can be used as AFR. • Develop legislation on AFR to focus on emission limits, rather than the input characteristics of waste streams. Ensure emissions monitoring frequency for AFR use in cement kilns is regulated. • To ensure acceptance of AFR use by the cement industry, address public and market barriers for AFR and co-processing through modified regulation and awareness-raising campaigns and through industry training and education. • Develop policy and guidelines to facilitate inter-state transportation of AFR. • To increase use of blended cement, improve the quality of fly ash through efficient coal blending systems and controlled coal combustion techniques in Indian thermal power plants.
Ministry of Finance	• Deploy various sources of green finance (*e.g.* Clean Technology Fund) within industry (public and private sector) to ensure uptake and proliferation of low-carbon technologies. • Sustain funding for the development and deployment of new transformational technologies. • Ensure financing is available for the piloting and demonstration of carbon capture and storage.
Ministry of New and Renewable Energy	• Grant renewable energy status to WHR systems, and ensure it is financially viable through appropriate incentives. • Reward clean energy investments *e.g.* through renewable energy certificates. • Develop policy and fiscal incentives for renewable energy. • Enable inter-state export of renewable energy through the national grid with lower wheeling charges to facilitate the installation of renewable energy generation units for cement industry captive power requirements.

Stakeholders	Action item
Ministry of Power (incl. Bureau of Energy Efficiency)	• Ensure effective implementation of the PAT scheme and its continuation in subsequent cycles. • Provide incentives and loan guarantees to support investments for technologies that improve thermal and electrical efficiency, including adoption of best available technology for new plants, retrofitting of old plants and to enable the implementation of WHR. • To increase use of blended cement, improve the quality of fly ash through efficient coal blending systems and controlled coal combustion techniques in Indian thermal power plant.
Ministry of Science and Technology (incl. Fly Ash Mission)	• Put in place a support mechanism for the development and deployment of new transformational technologies. • Facilitate transportation of blending materials between the source and the cement plant. • Oversee a near-term approach to facilitate development of carbon capture and storage. • Launch a public awareness campaign for carbon capture and storage.
Ministry of Steel	• Create an economically viable infrastructure to augment steel plants and granulate all blast furnace slag generated so it can be used in the cement industry and therefore increase blending ratios.
Ministry of Urban Development	• Develop and implement regulation on municipal solid waste collection and segregation.
Planning Commission	• Ensure development of Five Year Plans incorporates findings from Low-Carbon inclusive Growth analysis and other relevant studies to guide policy decisions towards incentivizing and facilitating low-carbon growth.
Cement manufacturers	• Conduct cement plant-level assessment of low-carbon technology implementation and establish plant-level action plans to accelerate the rate of implementation of all levers outlined in this roadmap. • Share global and national experiences on low-carbon technologies *e.g.* AFR to avoid the need for repeat testing in India. • Deploy existing state-of-the-art technologies in new cement plants, and retrofit existing plant with energy efficiency equipment when commercially viable. • Improve consumer awareness on cement characteristics and applications, and promote the use of blended cement. • Where regulatory framework is supportive, install WHR systems in new and refurbished plants.
Industry associations	• Gather reliable industry-level energy and emissions data to track performance and identify benchmarks. • Disseminate technical competence on low-carbon technologies *e.g.* on co-processing different kinds of AFR at workable levels and share information on AFR R&D already undertaken elsewhere, which identifies the OH&S risks of AFR, and how to mitigate them. • Engage in international collaboration for carbon capture and storage. • Drive a major thrust in R&D to advance the newer types of low-carbon cement from pilot to demonstration scales. • Create awareness among industry about the various funds or loan schemes in India, and about the financial incentives, fiscal benefits, etc., for adopting low-carbon technologies.

Stakeholders	Action item
Academic / research institutions / equipment manufacturers	• Conduct R&D to identify the likely emissions of any specific AFR material in any given combustion condition; and communicate results. • Enhance R&D to improve the uptake of existing low-carbon technologies *e.g.* on use of pond/dump ash deposits in blended cement; on demonstrating the possible extent of clinker substitution in cement; on the use of non-granulated blast furnace slag; on enhancing lime reactivity of dump/pond ash and making non-conforming fly ash reactive, and ensure adequate R&D on the blending activation process. • Conduct research to support the maximisation of power generation from already-proven WHR systems to help make overall economics of implementation attractive; and conduct R&D to promote and increase the use of appropriate technology. • Drive the emergence of transformational technologies. • Conduct R&D on fuel cells and large-scale adoption of futuristic comminution technologies. • Conduct R&D on carbon capture and storage to help industry move through pilot to demonstration phase to widespread implementation.
Multilateral development banks (MDBs), export credit agencies and local finance institutions	• Commit to invest in climate change mitigation and reflect this in their strategies (MDBs). • Work jointly with local finance institutions to develop finance mechanisms for investments in energy efficiency and other low-carbon technologies. Concessional climate funds should be used to leverage local private investments (MDBs). • Blend concessional climate funds with commercial funds resulting in a variety of financial products for programs and technologies which contribute to the demonstration, deployment and transfer of low-carbon technologies (similar to those identified in this roadmap) having potential for greenhouse-gas emissions reduction (MDBs). • Provide attractive funding or ensure loan guarantees for investments in low-carbon technologies (export credit agencies and MDBs). • Make available CDM and other carbon finance schemes to fund carbon capture and storage. • Work together with the cement industry to better understand changes in funding requirements of a low-carbon cement sector and funding opportunities of such a transition.

Annex A: Glossary

Biomass: any organic, *i.e.* decomposing, matter derived from plants or animals available on a renewable basis. Biomass includes wood and agricultural crops, herbaceous and wood energy crops, municipal organic wastes as well as manure.

Blended cement: portland cement mixed with clinker substitutes.

Carbon leakage: an increase in CO_2 emissions in one country as a result of 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. Cement acts as a binding agent when mixed with sand, gravel and/or crushed stone and water to make concrete. While cement qualities are defined by national standards, there is no worldwide, harmonised definition and/or standard for cement. In the WBCSD CSI Protocol and the GNR database, "cement" includes all hydraulic binders that are delivered to the final customer, *i.e.* all types of Portland, composite and blended cements, plus ground granulated slag and fly ash delivered to the concrete mixers, but excludes clinker.

Clinker: an 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.

Comminution: a process in which solid materials are reduced in size, by natural or industrial processes including crushing and grinding, or a process in which useful materials are freed from embedded matrix materials. For industrial purposes this takes place to increase surface area of solids.

Co-processing: the use of waste materials in industrial processes, *e.g.* cement, as a substitute for primary fuel or raw materials.

Fly ash: exhaust-borne particulates generated and captured at coal-fired power plants.

Geopolymer cement: is manufactured with chains or networks of mineral molecules producing 80% to 90% less CO_2 then OPC.

Ordinary Portland cement (OPC): the most common type of cement, consisting of over 90% ground clinker and about 5% gypsum.

Petcoke: or, petroleum coke is a carbon-based solid derived from oil refineries.

Pozzolana: a material, when combined with calcium hydroxide, exhibits cementitious properties.

Precalciner: a system which comes before the rotary kiln in the cement manufacturing process when most of the limestone calcination is accomplished, making the process more energy-efficient.

Sectoral approach: a combination of policies and measures developed to enhance efficient, sector by sector GHG gas mitigation within the UNFCCC. 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 chance.

Dry kiln: equipment that produces clinker without using a water/limestone slurry mix as the feedstock.

Wet kiln: equipment that produces clinker using water/limestone slurry as the feedstock.

Annex B: Abbreviations, acronyms and units of measurement

Abbreviations and acronyms

2DS	2°C Scenario
6DS	6°C Scenario
AFBC	atmospheric fluidised-bed combustion
AFR	alternative fuels and raw materials
Al_2O_3	alumina
BAT	best available technologies
BEE	Bureau of Energy Efficiency (India)
BIF	Boiler and Industrial Furnace
BIS	Bureau of Indian Standards
$CaCO_3$	calcium carbonate
CAPEX	capital expenditure
CCS	carbon capture and storage
CDM	Clean Development Mechanism
CFBC	circulating fluidised-bed combustion
CII	Confederation of Indian Industry
CMA	Cement Manufacturers Association (India)
CO_2	carbon dioxide
CPP	captive power plant
CSI	Cement Sustainability Initiative
ESCerts	Energy Savings Certificates (India)
ETP 2012	*Energy Technology Perspectives 2012*
EU	European Union
FAKS	fluidised-bed advanced cement kiln system
Fe_2O_3	iron oxide
FMCG	fast-moving consumer goods
GBFS	ground blast furnace slag
GDP	gross domestic product
GNR	Getting the Numbers Right
IEA	International Energy Agency
IFC	International Finance Corporation
INR	Indian rupee
IREDA	Indian Renewable Energy Development Agency
MDB	multilateral development bank
LCA	life-cycle assessment
MgO	magnesium oxide
MNRE	Ministry of New and Renewable Energy
MRV	monitoring, reporting and verification
MSW	municipal solid waste
NAMA	nationally appropriate mitigation action
NAPCC	National Action Plan on Climate Change
NCB	National Council for Cement and Building Materials (India)
NGO	non-governmental organisation
NOx	nitrogen oxide
NMEEE	National Mission for Enhanced Energy Efficiency (India)
OECD	Organisation for Economic Co-operation and Development
OH&S	operational health and safety
OPC	Ordinary Portland Cement
PAT	Perform, Achieve and Trade (India)
PLC	Portland Limestone Cement
PPC	Portland Pozzolana Cement
PPP	public-private partnership
PRGFEE	Partial Risk Guarantee Fund for Energy Efficiency (India)
PSC	Portland Slag Cement
PV	photovoltaic
R&D	research and development
RDF	refuse-derived fuel
RE	renewable energy
REC	Renewable Energy Certificate
RPO	Renewable Purchase Obligation
SiO_2	silica
TSR	thermal substitution rate
ULCOS	Ultra-Low CO_2 Steelmaking
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States dollar
US-EPA	United States Environmental Protection Agency
VCFEE	Venture Capital Fund for Energy Efficiency (India)
WBCSD	World Business Council for Sustainable Development
WHR	waste heat recovery

Units of measure

°C	degree Celsius
cm	centimetre
GJ	gigajoule (10^9 joules)
Gt	gigatonne (10^9 tonnes)
GWh	gigawatt hour (10^9 watt hour)
kcal	kilocalorie (10^3 calories)
kg	kilogramme (10^3 grammes)
kWh	kilowatt hour (10^3 watt hour)
MJ	megajoule (10^6 joules)
Mt	million tonne (10^6 tonnes)
MTPA	million tonne per annum
Mtoe	million tonne of oil equivalent
MW	megawatt (10^6 watt)
PJ	petajoule (10^{15} joules)
t	tonne
tpd	tonne per day

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Annex D: Model methodology and assumptions

As part of the IEA global work on energy use and emissions reduction, industry is modelled using a stock accounting model that covers (in detail) five energy-intensive sectors: iron and steel, cement, chemicals and petrochemicals, pulp and paper, and aluminium. Demand is estimated based on country (or regional-level) data for GDP, disposable income, short-term industry capacity, current materials consumption, demand saturation rates and resource endowments. Total production is simulated by factors such as process, age structure (vintage) of plants and stock turnover rates. Overall production is similar across scenarios, but means of production differ considerably. For example, the same level of crude steel production is expected in both the 6DS and 2DS, but the 2DS reflects a much higher use of scrap (which is less intensive than production from raw materials). Each industry sub-model is designed to account for sector-specific production routes.

Changes in the technology mix and efficiency improvements are driven by external assumptions on penetration of BATs at each given time. The analysis incorporates the projected relative cost of those technologies, as well as how marginal abatement costs in industry compare to those in other sectors during the given time period. Thus, results are sensitive to assumptions on how quickly physical capital is turned over and to how effective incentives are for the use of BATs for new construction.

The five industry-specific sub-models have the same basic structure: each comprises three different "modules": the basic assumptions and input module, the technology specification module, and the output module where detailed energy consumption and emissions data are presented.

The basic assumptions and inputs

The starting point of the model is the basic assumption and input module. This module comprises assumptions on the per capita demand of materials (such as crude steel, cement and aluminium) used to derive total production by each region. The materials assumptions are developed using different macro-economic drivers such as GDP, income, expected capacity addition, the current consumption and production of materials and resource endowment in a region.

The cement demand forecast is a crucial parameter to assess potential energy and emissions reduction. In the IEA *ETP*-industry model, the cement demand intensity in India (expressed in kilogramme of cement per capita) is projected to 2050 using the expected growth in GDP per capita, and the expected elasticity of cement demand and per capita income. The elasticity, which decreases through time to account for an increase in infrastructure maturity, is assumed to be higher in the High-Demand Case.

Table D.1: Key parameters of the basic assumptions and input module for India

	2010	2015	2020	2025	2030	2035	2040	2045	2050
GDP (billion 2010 USD at purchasing power parity)	4 060	5 993	8 337	11 121	14 727	19 366	24 999	31 188	37 721
Population (million)	1 225	1 308	1 387	1 459	1 523	1 580	1 627	1 665	1 692
Per-capita income (2010 USD at purchasing power parity/ capita)	3 316	4 581	6 011	7 623	9 667	12 258	15 365	18 737	22 294
Cement demand intensity (kg/capita)									
Low-Demand Case	188	257	309	352	400	431	446	462	467
High-Demand Case	188	270	364	457	565	652	735	784	812
Cement production (Mt)									
Low-Demand Case	217	324	416	502	598	670	715	759	780
High-Demand Case	217	341	492	653	848	1 017	1 183	1 293	1 361

The technology specification

The initial historical values for the clinker-to-cement ratio, specific electricity and thermal consumption and fuel shares are provided to the model. The changes in these parameters between the base year and 2050 are related to the dynamic of the production and the assumptions on the rate of implementation of technologies and options.

The production derived in the first module is used to develop estimates of how many new units will be required. Based on average lifespan of each technology (or plants), this module will also calculate the number of plants refurbished and retired between each period specified (the IEA *ETP*-industrial model is working in steps of five years).

The model also takes into consideration the relative intensity of the new, refurbished and retired units during each period of time.

In this module, there are noticeable difference between the 6DS and the 2DS:

- the 2DS assumes that all new industrial plants are build with BAT (in the 6DS, there is a mix of "average" and BAT units);
- the 2DS has a quicker turn-over, as plants are refurbished (or, in some case, retired) before their anticipated end-of-life;
- the mix of fuel remains relatively stable in the 6DS; the 2DS assumes a shift to AFR; and
- the 2DS assumes the use of CCS.

Table D.2: Main output of the technology specification module

		2DS Low-Demand Case				*2DS High-Demand Case*			
	2010	2020	2030	2040	2050	2020	2030	2040	2050
Cement-to-clinker ratio	0.74	0.70	0.64	0.60	0.58	0.70	0.64	0.60	0.58
Clinker production (Mt)	161	290	382	429	449	342	544	713	794
Thermal intensity (kcal/kg clinker)	725	709	694	685	680	703	690	682	678
Electric intensity (kWh/t cement)	80	76	73	72	71	75	72	71	70
Biomass and waste fuel share	0.6	5	19	24	25	5	19	24	25
Coal share	98	93	78	71	71	93	78	73	70
Oil share	1.4	1.2	1.2	2.2	0.9	1.2	1.0	0.7	0.6
Natural gas share	0.0	0.7	1.4	2.1	2.8	0.7	1.4	2.1	4.2
% carbon capture	0%	1%	9%	17%	25%	2%	10%	20%	28%

Note: Electric intensity of cement production does not include the reductions that may come from the use of WHR.

The outputs

Energy consumption in the cement sector is calculated from clinker and cement production and intensity values. CO_2 emissions are calculated using fuel-specific and process-related emission intensity.

Table D.3. Emission factors used in this roadmap

Coal	4.36	tCO_2/toe
Oil	3.24	tCO_2/toe
Natural gas	2.34	tCO_2/toe
Process emissions	0.5071	tCO_2/t clinker
Alternative fuels	composition	emission factor (tCO_2/toe)
Tyres	40%	3.08
Plastics	20%	3.08
Biomass/renewable	40%	0

Investments

The investment analysis presented in this roadmap is only a partial assessment of the investment needed for energy-consuming equipment. Only major energy-consuming equipment and devices have been covered, as sufficient data do not exist to accurately project the quantity and price of a wide range of small energy-consuming devices. The boundary placed on investment costs is also in question.

As a result of this, given the more widely available information on the marginal cost of energy efficiency options, the relative increase or decrease in investment needs in the 2DS compared to the 6DS should be treated with greater confidence than the absolute level of investments.

This roadmap estimates that investments required to build a new plant amount to approximately USD 200/t clinker capacity. However, it is assumed that reaching BAT or target plant level would require additional investment of 10% to 25%. The roadmap also assumes that investments between USD 27/tCO_2 and USD 33/tCO_2 will be required for clinker substitutes and between USD 15 and USD 20/t clinker capacity for AFR. Additional investments of USD 75/tCO_2 to USD 150/tCO_2 will be required for the implementation of CCS.

Annex E: Definition of reference, best available technology and target average performance

Parameter	Unit	Reference plant	BAT plant	Target average performance in 2050
Clinker capacity	mMTPA	1.5	1.5	1.5
Cement capacity	mMTPA	2.10	2.30	2.70
Kiln capacity	tpd	4 500	4 500	4 500
Kiln type		Modern, dry, precalciner preheater	Modern, dry, precalciner preheater	Modern, dry, precalciner preheater
Number of stages in preheater		5	6	6 or 7
Single string/double string		Single	Single	Single
Type of cooler		Reciprocating grate cooler	Latest generation cooler	Latest generation cooler
Raw meal to clinker factor		1.5	1.5	1.5
Specific thermal energy consumption	kcal/kg clinker	715	685	680
Specific thermal energy consumption	MJ/Mt clinker	2 990	2 865	2 846
Clinker factor	ratio	0.72	0.65	0.58
Specific power production	kWh/Mt cement	75	69.5	69.5
Raw mill	kWh/Mt cement	16	15.5	15.5
Coal mill	kWh/Mt cement	5	5	5
Pyro processing	kWh/Mt cement	24	21	21
Up to clinkerisation	kWh/Mt cement	45	41.5	41.5
Cement grinding	kWh/Mt cement	30	28	28
AFR usage	TSR %	1	5	25.3
Cost of electricity	INR/kWh	4.5	5	6
Fuel cost for cement kiln	INR/Mkcal	800	900	1 000
Gross CO_2 emission per Mt cementitious product	$kgCO_2$/Mt cementitious product	720	665	560

Reference plant has been considered to be in the top 20 percentile of the Indian cement industry. More than 50% of the capacity of the Indian cement industry is less than ten years old and all recent plants have had high-level energy efficiency practices incorporated, therefore, the reference plant is considered for all emission reduction estimates in the technology papers (add reference here). Industry, as a whole, may achieve these average numbers by the year 2020. Target plant incorporates all wish list ideas and practices and could depict the average performance of the Indian cement industry by the year 2035.

Annex F: Process of roadmap development

January 2010

IEA workshop on International Comparisons of Industrial Energy Efficiency with Indian and international experts.

Establishment of India Energy Technology Perspectives (ETP)-expert group on industry.

August 2010

Launch of *ETP 2010* in India and review of the draft document "*Energy Transition for Industry: India and the Global Context*".

Initial discussion on development of a joint roadmap for the cement industry.

January to March 2011

Preparatory meetings with partners and CSI companies, and establishment of expert working group with nine CSI member companies in India and three member companies in Europe.

Funding and support structure agreed.

May 2011

Initiation meeting with all partners, selection of collaboration partners.

Agreement on modelling assumptions, roadmap objectives and parameters.

June 2011

Stakeholder dialogue on low-carbon growth to agree on the scope and technologies to be covered in industry technical papers (33 industry experts gathered in Mumbai and 25 in Delhi).

July to December 2011

Data collection takes place to obtain current energy and emissions data from 65% of the Indian cement industry through CSI's 'Getting the Numbers Right' (GNR) database, and **individual surveying** of industry in India by CII for use in modelling by the IEA.

January to September 2012

Modelling by the IEA with continuous reiterations following input from industry and other stakeholders.

September 2011 to June 2012

Continued working group meetings across India to review and refine a set of 27 technical papers, including input from industry experts from outside India, as well as equipment suppliers, industry associations, research institutions, and other industries from India.

Outreach to CSI's 24 global members at CSI annual forum in Thailand.

Formal engagement established between CSI Secretariat and Cement Manufacturers Association.

November 2011

Outreach at NCB's annual seminar and in CSI CEO meeting at global level. Specific webpage created on roadmap.

January 2012

Stakeholder dialogue on policy and financing to obtain input on policy and financing barriers and support for implementation of the technical papers. Approximately 50 experts from financial institutions, research organisations, and government agencies participated. Simultaneous **launch of technical paper external consultation period**.

January to September 2012

Modelling and drafting of roadmap completed and by all partners with extensive internal and external consultation periods for feedback.

"Phase II" structure and parameters agreed.

January 2013

Launch of the roadmap and technical papers.

"Phase II" begins and plants identified.

Roadmap partners

International Energy Agency (IEA)

The 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.

The IEA carries out a comprehensive programme of energy co-operation among 28 of the 34 OECD 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; and
- to assist in the integration of environmental and energy policies, including those relating to climate change.

World Business Council for Sustainable Development (WBCSD) Cement Sustainability Initiative (CSI)

The CSI is a global effort by 25 major cement producers with operations in more than 100 countries who believe there is a strong business case for the pursuit of sustainable development. Collectively these companies account for about one-third of the world's cement production and range in size from very large multinationals to smaller local producers.

The members of the CSI – a voluntary business initiative from around the world – have been addressing climate change issues for more than a decade. The CSI is currently working to understand the impact of cement's whole life cycle, *i.e.* from quarrying limestone or obtaining alternative raw materials from other industries, to the end product as concrete and recycled aggregates.

To date, the CSI remains one of the largest global sustainability programs ever undertaken by a single industry sector. To find out more, visit www.wbcsdcement.org.

In India, nine member companies collaborated on the roadmap development. They are: ACC Ltd. (project Co-Chair), Ambuja Cements Ltd., HeidelbergCement India Ltd., Lafarge India Private Ltd., My Home Industries Ltd. – CRH, Shree Cement (project Co-Chair), Shree Digvijay Cement Co Ltd. – Cimpor Group, UltraTech Cement Ltd. (project Co-Chair) and Zuari Cement. Since starting the roadmap, Dalmia Bharat Cement and Jaypee Cement have also joined CSI.

Supported by

International Finance Corporation (IFC)

IFC, a member of the World Bank Group is the largest global development institution focused exclusively on the private sector. We help developing countries achieve sustainable growth by financing investment, providing advisory services to businesses and governments, and mobilising capital in the international financial markets. In fiscal 2011, amid economic uncertainty across the globe, we helped our clients create jobs, strengthen environmental performance, and contribute to their local communities - all while driving our investments to an all-time high of nearly USD19 billion. For more information, visit www.ifc.org

IFC in South Asia

To grow opportunities for the underserved, IFC in South Asia has concentrated on low-income, rural, and fragile regions while building infrastructure and assisting public-private-partnerships; facilitating renewable energy generation; promoting cleaner production, energy and water efficiency; supporting agriculture and sustainable forestry; creating growth opportunities for small businesses; reforming investment climate; encouraging low-income housing; and making affordable healthcare accessible. Through these strategic interventions in the region, IFC aims to promote economic inclusion at the base of the pyramid, particularly in the low-income states of India; help address climate change impacts; and encourage global and regional integration .IFC focuses on building on its experiences to engage in working with the private sector in the region to develop measures that will increase incomes for the poor and small businesses. IFC has tried to support projects that are difficult in nature, first of its kind and reform oriented. We are increasingly being engaged by governments when they see we bring unique knowledge, experience and access to a wide network of investors, and sector expertise.

IFC Sustainable Business Advisory promotes sustainable business practices among firms, to promote investment practices addressing climate change. Resource Efficiency teams work with firms and at the sector level to save costs, prevent waste, and reduce greenhouse-gas emissions through more efficient use of energy, water and materials.

In collaboration with

Confederation of Indian Industry (CII)

The Confederation of Indian Industry (CII) works to create and sustain an environment conducive to the growth of industry in India, partnering industry and government alike through advisory and consultative processes.

CII is a non-government, not-for-profit, industry led and industry managed organisation, playing a proactive role in India's development process. Founded over 116 years ago, it is India's premier business association, with a direct membership of over 8 100 organisations from the private as well as public sectors, including small and medium enterprises and multinationals, and an indirect membership of over 90 000 companies from around 400 national and regional sectoral associations.

www.cii.in

CII - Sohrabji Godrej Green Business Centre (CII - Godrej GBC), a division of CII is India's premier developmental institution, offering advisory services to the industry on environmental aspects and works in the areas of green buildings, energy efficiency, water management, environment management, renewable energy, green business incubation and climate change activities.

www.greenbusinesscentre.com

National Council for Cement and Building Materials (NCB)

The National Council for Cement and Building Materials (NCB) is an apex R&D organisation functioning under the administrative control of Department of Industrial Policy and Promotion, Ministry of Commerce and Industry, Government of India. NCB, in the service of the nation, is devoted to technology development and transfer, testing and calibration, human resource development and consultancy services for the benefit of cement and construction industry for about the last 50 years. Its multi-disciplinary activities are performed in an integrated and co-ordinated manner through its two larger units located at Ballabgarh (near Delhi) and Hyderabad (Both ISO: 9001-2008 Certified) and the third unit at Ahmedabad, guided by the six corporate centers.

www.ncbindia.com

Disclaimer

This report is the result of a collaborative effort between the IEA and the World Business Council for Sustainable Development's (WBCSD) Cement Sustainability Initiative (CSI). The individual member companies, subsidiaries and joint ventures in India that make up the CSI have participated in the development of this report, but have made no specific commitments on implementation of any technologies described in the report. Users of this report shall take their own independent business decisions at their own risk and, in particular, without undue reliance on this report. Nothing in this report shall constitute professional advice, and no representation or warranty, express or implied, is made in respect to the completeness or accuracy of the contents of this report. Neither the WBCSD, nor the IEA accepts any liability whatsoever for any direct or indirect damages resulting from any use of this report or its contents. A wide range of experts reviewed drafts. However, the views expressed do not necessarily represent the views or policy of either the CSI, or their member companies, or of the IEA, or its individual member countries. For further information, please contact: technologyroadmapscontact@iea.org or cement@wbcsd.org.

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The roadmap is the result of a collaborative effort between the International Energy Agency (IEA) and the World Business Council on Sustainable Development Cement Sustainability Initiative (WBCSD CSI). WBCSD and IEA wish to thank the International Financial Corporation (IFC), a member of the World Bank Group, for part-funding this initiative and for their valuable contribution in the development on the roadmap content.

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IEA Publications, 9 rue de la Fédération, 75739 PARIS CEDEX 15
Printed in India by Lustra Print Process Pvt. Ltd., January 2013
ISBN: 978-2-940521-00-5

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Back cover photo (large): ACC, concrete arterial road surface of Marine Drive, Mumbai, India;
Back cover photo (small): Twigg, aggregate trucks in Andhra Pradesh, India.

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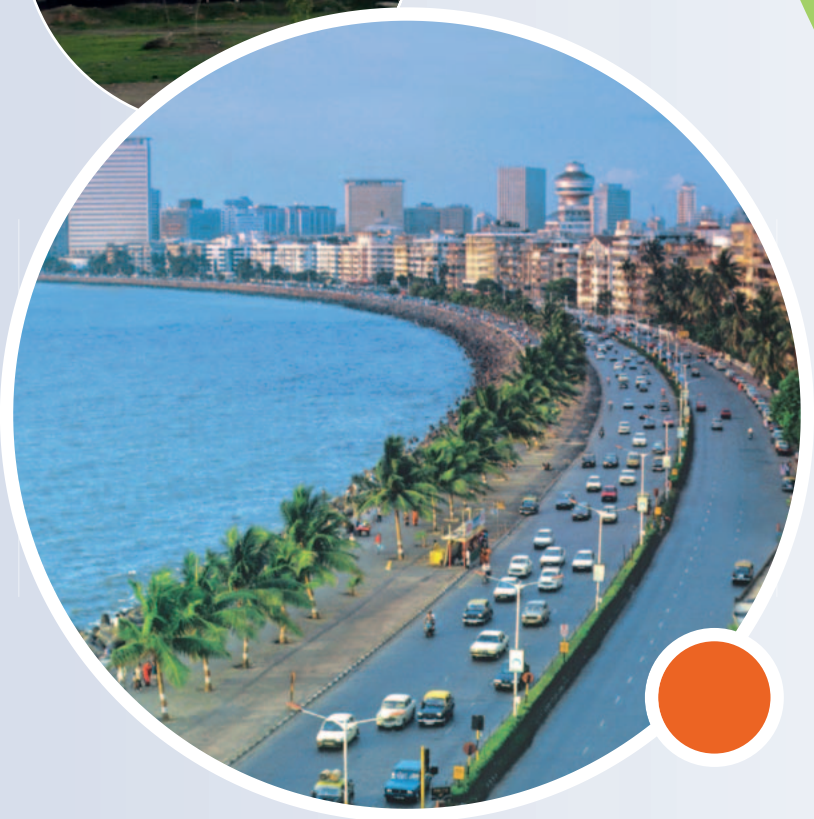

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