GREEN INITIATIVES IN CEMENT INDUSTRIES OF RAJASTHAN

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A B S T R A C T: The Indian cement industry, the second largest cement producer in the world has a total installed capacity and actual cement production (2017-18) of 455 MTPA and 285.68 MTPA respectively. Rajasthan is having around 30 MTPA cement production capacity. Major cement plants are Ultratech,ACC Lakheri, Ambuja, Shree Cement, India cement, Shriram. Between2000 and 2010, annual production of cement in India rose from 95 Mt to 220 Mt, an average increase of almost 10% per year. India's population is set to increase by almost 40% between2010 (1.2 billion) and 2050 (1.7 billion). Over the same period, the rapid urbanization seen recently is expected to accelerate, and gross domestic product (GDP) is expected to increase fromUSD 4,060 billion in 2010 to USD 37,721 billion in 2050. These trends, alongside anticipatedlarge-scale infrastructure development such as highways, ports, dams and new airports, will driveup the demand for concrete. The growth in domestic cement demand is expected to remain strong, rising to between 465 kg/capita and 810 kg/capita in 2050. Annual cement production isestimated to reach between 780 Mt ('low demand scenario') and 1,360 Mt ('high demandscenario') by 2050. Under the high demand case, India could become the world's largest cementproducer before 2050. To ensure these growth projections do not lead to substantial rises ingreenhouse gas emissions, serious efforts are required to enable low-carbon technology andprocesses to become the norm in cement manufacturing going forward.

In line with the Indian cement industries, Rajasthan cement Industries also put efforts to reduce its carbon footprint by adopting the best available technologies and environmental practices are reflected in the achievement of reducing total CO2 emissions to an industrial average of 0.719 tCO2/t cement in 2010 from a substantially higher level of 1.12 tCO2/t cement in 1996. In order to further reduce CO2 emissions, four technological key levers have been identified. These levers are increased use of AFR, improvement in thermal and electrical energy efficiency, reduction in clinker to cement ratio, and application of newer technologies. In addition, recovery of waste heat for co-generation of power and captive power generation can contribute to emissions reductions at a plant level. These form the basis of a low carbon technology roadmap for the Indian cement industry launched in February 2013. Technical, financial and policy barriers that need to be addressed to facilitate the industry to achieve this have also been highlighted. Ultratech has established solar power plants also and ACC is utilizing AFR.

The potential of these individual levers in low/high demand scenarios of the International Energy Agency's 2 degree scenario (2DS) and 6 degree scenario (6DS), when coupled with appropriate policy initiatives and interventions, to achieve emissions level of 0.35tCO2/t of cement by 2050, a reduction of 45% over current levels. Of the full emissions reduction potential proposed in the roadmap, 10% is estimated to come from AFR use, 4% from efficiency improvements, 45% from increased blending, and 41% from new technologies.

This multi-stakeholder initiative had significant contributions from various leading organizations such as World Business Council for Sustainable Development (WBCSD)'Cement Sustainability Initiative (CSI members representing around 65% of cement production capacity in India),International Energy Agency (bringing in their expertise in scenario-building, modeling, androadmap development), and CII and NCB (developing technical papers and providing inputs tothe roadmap development) and IFC (bringing in a financial perspective, technical expertise and financial support).

Key Word- Environment, occupational health & safety, cement.

Introduction

In Rajasthan state there are various cement plants of different companies are operating .Which includes Ultretech ,ACC, Ambuja, Shree cement, India cement,Shriram, Nuvoco,Nirmex etc.

The north zone of India including Rajasthan is contributing around 21% in cement manufacturing. All major cement companies of Rajasthan is utilizing alternate fules and raw materials ,working on NOx and Sox reduction through various innovative latest technologies and established solar power plants. They are working on reduction of carbon foot prints through focus on technological up-gradation and regular on line monitoring .

While the industry average energy consumption is estimated to be about 725 kcal/kg clinker thermal energy and 80kWh/t cement electrical energy, the highest thermal and electrical energy consumptions presently achieved are about 667 kcal/kg clinker and 67 kWh/t cement respectively. These are comparable to the best reported figures of 660 kcal/kg clinker and 65 kWh/t cement in a developed country like Japan. Out of the above, 93 large cement plants have ISO-9000 (Quality Management System) certification, 64 plants ISO-14000 (Environmental Management System) certification and 44 plants OHSAS- 18000 (Occupational Health and Safety Management System) certification. These accreditations strongly manifest the industry's commitment to quality, environment, health and safety issues. In this regard, emissions CO2(one of the main Greenhouse gases (GHG)), are generated from the decomposition of carbonate raw materials (50-55%),burning of fossil or alternate fuels in cement kilns (40-45%) or grid or captive thermal power at cement plants (up to 10%). This is a major environmental issue.

The Rajasthan 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 CO2 emissions. In order to further reduce CO2 emissions, four technological key levers have been identified which can contribute to a reduction in CO2 emissions. These form the basis of a low-carbon technology roadmap for the cement industry launched inFebruary 2013. These levers include increased use of **Alternative Fuels and Raw materials (AFR**), **improvement in thermal and electrical energy efficiency, reduction in clinker to cement ratio**, and **application of newer technologies**. In addition, recovery of waste heat for co-generation of power and captive power generation can contribute to emissions reductions at a plant level. This paper highlights the potential of these individual levers in low/high demand scenarios of the International Energy Agency's 2 degree scenario (2DS) and 6 degree scenario (6DS), when coupled with appropriate policy initiatives and interventions, to achieve emissions level of 0.35 tCO2/t of cement by 2050.

Key Findings

In line with the Indian cement industries, cement major cement plants of Rajasthan are one of the efficient in the world, yet, because the manufacturing process relies on the burning of limestone (calcium carbonate), it still produces approximately 7% of India's total man-made carbon dioxide (CO_2) emissions

- The major cement plants of Rajasthan have made strong efforts to reduce its carbon footprint by adopting the best available technologies (BAT) and environmental practices. Through this it has achieved a reduction in total greenhouse gas (GHG) emissions to an industrial average of 0.719 tonne (t) of CO_2/t cement (direct and indirect emissions)from a substantially higher level of 1.12 tCO_2/t cement .

- In a business-as-usual scenario, CO_2 emissions from the Indian cement industry are projected to reach between 485 million tonne (Mt) of CO_2 and 835 MtCO_2 by 2050,about 20% of India's expected emissions in 2050. This represents an increase of between 255% to 510% increase compared to current emissions .Being around 15% contributor Rajasthan will also be major contributor if suggested majors not adopted.

- This roadmap outlines technologies, policy frameworks and investment needs that could reduce CO_2 intensity in the Indian cement industry by about 45% by 2050, from 2010 level. This would limit CO_2 emissions growth to between 100% (low-demand scenario) and 240% (high-demand scenario) compared to the current level

- Key levers to reduce emissions in the Rajasthan cement plants are increased rates of blending and alternative fuel use, 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.

- Energy efficient captive power plants (CPP) offer important emissions reduction opportunity. Assuming that CPP will continue to account for 60% of the cement electricity needs in 2050, as much as 175 MtCO2 could be saved through efficiency improvement

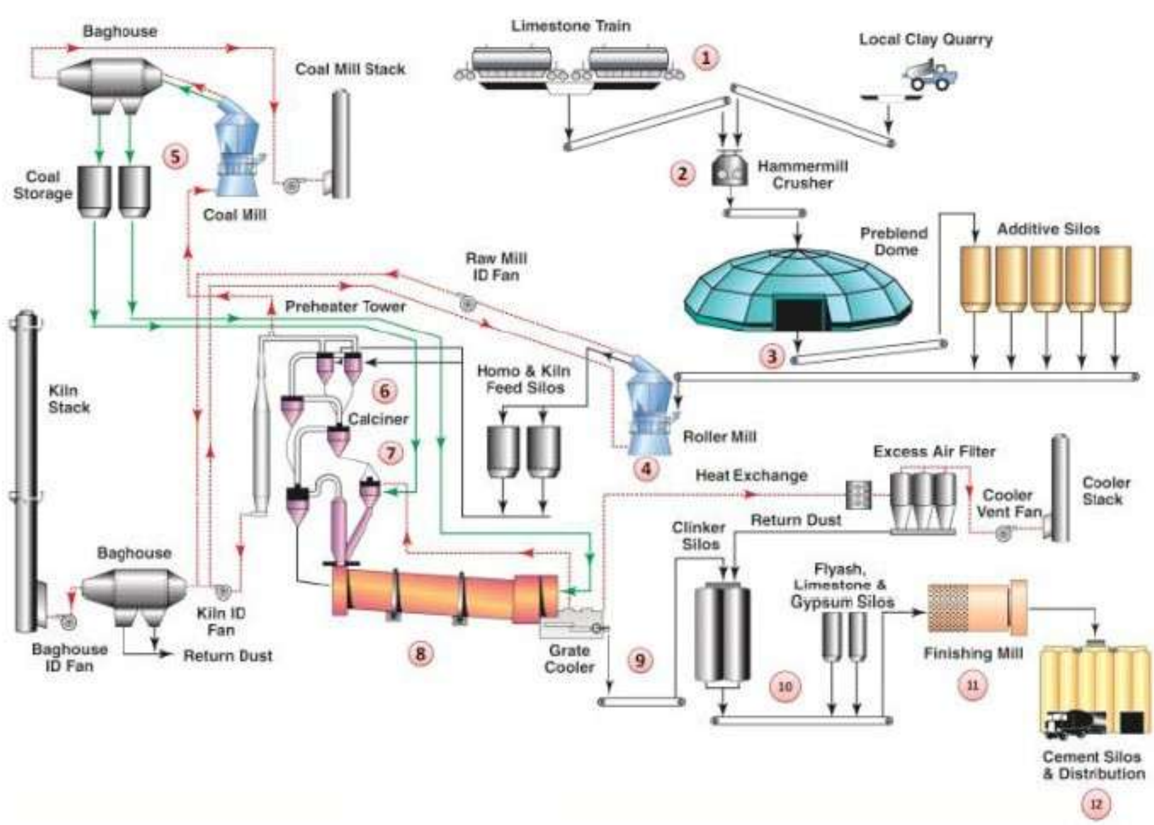
- To ensure widespread deployment and implementation of such technologies in the future, social acceptance, political will and policy development, and financial mechanisms must be supportive

- The additional investment requirements to reduce growth in CO_2 emissions in the Indian cement industry are between Indian Rupee (INR) 170 000 crore2 and INR 500 000 crore (United States dollar [USD] 34 to USD 100 billion), or 20% to 30% higher than in a business-as-usual scenario.

Overview of cement manufacturing

Cement is the essential 'glue' in concrete, a fundamental building material for society's infrastructure around the world.
Surface mining/quarrying raw materials

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



Naturally occurring calcareous deposits such as limestone, marl or chalk provide calcium carbonate (CaCO3) comprise the raw materials of cement. These are extracted from surface mines/quarries, often located close to the cement plant. Very small amounts of "corrective" materials such as iron ore, bauxite, shale, clay or sand may be needed to provide extra iron oxide (Fe2O3), alumina (Al2O3) and silica (SiO2) to adapt the chemical composition of the raw mix to the process and product requirements.

Crushing
The raw material is mined and transported to the primary/secondary crushers and broken into 10 centimeters (cm) large pieces.

Prehomogenisation and raw meal grinding
In the prehomogenisation process, different raw materials are mixed to maintain the required chemical composition. 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.

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

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

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

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

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

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

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

Background: Low carbon technology roadmap
The International Energy Agency is leading the development of a series of energy technology roadmaps which aim to accelerate the development and deployment of the major technologies needed to reach the ambitious goal of limiting global temperature increases to 2 degrees Celsius. The IEA's approach involves engaging experts from industry, government and research institutes to work together with the IEA in elaborating an implementable strategy to accelerate the development and deployment of a given technology or realizing the energy and emissions reduction potential of a given industry sector. The roadmaps outline an action plan for specific stakeholders to show the short- and longer-term priorities needed to achieve deep emissions reduction.
In 2009, recognizing the urgency of identifying technologies to enhance the reduction of the energy use and CO2 intensity of cement production, CSI 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 cement roadmap, IEA and CSI, in collaboration with CII and NCB joined together to develop a roadmap specifically for the Indian cement industry, based on the Indian context.

UltraTech and ACC continued to work closely with other members of the Cement Sustainability Initiative (CSI) of the World Business Council for Sustainable Development (WBCSD) as well as a host of external stakeholders with technical expertise by the Confederation of Indian Industry (CII) and the National Council for Cement and Building Materials (NCBM) in the development of a technology road map for a low carbon economy for the Indian cement sector. The exercise is part funded by International Finance Corporation (IFC). Various papers were developed as part of the road map explaining opportunities to drive the industry towards a low carbon economy with thread- bare discussions on each and every paper, taking and improvising based on feedback from all stakeholders. ACC was Co-chair for the initiative along with UltraTech Cement and Shree Cement. The document was released during January 2013

Low carbon roadmap: Modeling and findings
The IEA Energy Technology Perspectives 2012 (ETP 2012) uses extensive modeling to examine possible scenarios of global energy demand in the future. Its 2°C Scenario aims at limiting the Increase in global average temperature to 2°C and examines how to achieve deep emission cuts to at least halve global emissions by 2050. The 6°C Scenario (6DS) serves as the baseline scenario which is largely an extension of current trends, with no effort to curb emissions. Under the 2DS, annual global industrial emissions would be 6.7 GtCO2 in 2050, about 20% less than current levels. For India, a detailed analysis was performed in collaboration with the Indian experts. The analysis indicated that total industrial emissions would reach between 0.8 GtCO2 and 1.1 GtCO2in 2050.
This would imply that total emissions in the cement sector would need to be limited to approximately 0.28 GtCO2 in 2050. This represents a direct emissions reduction of about 0.28tCO2/ t cement produced – from 0.63 tCO2/t cement in 2010 to 0.35 tCO2/t cement in 2050. Such a reduction in emission intensity would limit the growth in CO2 emissions from the cement industry to just a doubling despite a four-fold increase in production. The Indian cement road mapuses the IEA model to identify a vision for the industry to contribute to significant energy and emissions reduction and helps to evaluate the technologies needed to achieve this goal.
The key levers to reduce emissions in the Indian cement industry are increased use of alternative fuels, increased thermal and electrical energy efficiency, increased rates of blending leading to a reduction in clinker-to-cement ratio, a radical step change in new technology development to bring potential technologies such as carbon capture and storage from research and development to deployment and widespread implementation of waste heat recovery systems. The implementation of these technologies could lead to energy savings of at least 275 PJ equivalent to the currentindustrial energy consumption of Singapore or the Philippines. These levers have been describedin the next section of the paper.
In order to achieve these outcomes, certain policy interventions are required. These have been delineated in section 4.0 of this paper.

Potential technological options
Co-processing of Alternate Fuels and Raw Materials (AFR)
Firstly, co-processing of AFR in cement kilns creates a win-win situation for both the cement Industry and the stakeholders (waste generators, local administration and the society) owing to much lower environmental impact than disposal through incineration or landfill.
Various potential AFR include 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,

nonrecyclableplastics, textiles and paper residues, biomass (such as rice husk, coconut shells, groundnut shells, etc.), effluent treatment sludges from water and wastewater treatment plants andlime sludges from paper and allied industries, etc. just to name a few. The global average of AFRuse in the cement industry is currently 4.3% of total thermal energy consumption as against only0.6% in India. This number can be much higher (30% or more) in some countries having a longerexperience with AFR use, particularly in Europe for instance. With extensive national and globalexpertise available, the Indian cement industry is technically ready to adopt higher rates of AFR use.

The current key challenges in increasing the alternative fuel usage in the country are the absence of enabling policy guidelines, lack of waste pre-processing facilities that can help in improving the quality of waste (high organic nature) by maintaining consistency and limited awareness among waste generators and cement manufacturers. While at lower substitution levels (of <5%), alternative fuel substitution does not impact the plant productivity and energy consumption significantly, increased substitution requires significant investment for additional handling, storage, testing and feeding facilities in cement plants.

International experiences indicate increased thermal energy consumption with increase in thermal substitution rates. This may be attributed to higher gas flow rates due to higher moisture content and excess air requirement for burning alternative fuels. These requirements increase the specific power consumption of the kiln circuit and reduce the production levels if sufficient margin is not available in the design. Adopting the latest pre-processing, testing and firing technology and retrofitting the existing equipment can address the above concerns and can help cement plants to achieve the same levels of energy efficiency and productivity at increased substitution rates.

The Interim Report of the Expert Group on Low Carbon Strategies for Inclusive Growth of the Government of India proposes a fuel substitution rate of 5% by 2020 under the Determined Effort Regime and 10% under Aggressive Effort Regime; the adoption of Best Available Technologies(BAT) by smaller units could lead to an annual decrease of 1.8% in emission intensities. A estimated in Technology Roadmap for Indian Cement Industry, AFR can contribute to a reduction of between 21 million tonnes CO2 (Low-Demand Case) and 37 million tonnes CO2 (High-Demand Case) in the 2DS scenario compared to 6DS by 2050. These figures highlight the industry's capability and potential for CO2 reduction.

Increasing thermal and electrical energy efficiency

The second important lever is increasing the thermal and electrical energy efficiency. In line with Indian cement industry, cement industries in Rajasthan has been growing ; about 50% of Indian cement industry's capacity today is less than ten years old. These Industries has phased out several old technologies in the 1990s and 2000s.

Increasing energy costs and higher share of energy cost (about 40-50%) in overall manufacturing costs has driven Indian cement industry to adopt consistent efforts in reducing the energy consumption and maintaining competitive business advantage. Increased awareness levels, competition, continuous support from suppliers and service providers, information sharing and higher growth rates have helped plants to achieve world class standards. The average specific power consumption of the cement sector has reduced significantly from more than 100 kWh /MT cement in 1990's to 80 kWh/ MT cement in 2010. Some of the Indian cement plants are operatingat lowest possible electrical and thermal energy consumption levels such as 65 kWh / MT OPCand 685 kcal / kg clinker.

While some of the latest plants are operating with lowest energy numbers, the potential to further reduce the overall energy consumption and resulting carbon emissions is significant. Tremendous potential is available in both electrical and thermal energy areas for further reduction opportunities.

Typically, grinding of raw material (limestone grinding) and final product (cement grinding) consumes the major portion of electrical energy followed by fans. Adopting latest technology such as Vertical Roller Mills (wherever moisture content of feed materials is more than 5%) or ball mills with high pressure grinding roll (HPRG) systems with third generation classifiers, can help to achieve lower energy consumption levels. New generation centrifugal fans with more than 85% efficiency, fine tuning of existing fans in terms of head and flow, optimizing fan operating point to best possible efficiency zone, installation of medium voltage drives to avoid loses and flow control, are the other options available to reduce the energy levels.

Installation of advanced online automation systems for raw mix design, flame control, combustion control, grinding and plant operation can significantly reduce the energy consumption levels by stabilizing plant performance through reducing variations due to raw material characteristics, manual interventions, over margin, etc.

Utilisation of Computational Fluid Dynamic (CFD) technique for solving operational problems such as higher pressure drop, lower heat transfer, lower cyclone efficiency and poor material/flow distribution in the separators, mills and ducts is the developing area/tool for existing plants to optimize efficiency. The advantages of CFD are low investment, reduced down time, ability to provide multiple options for solving a given problem and better accuracy in predicting the anticipated benefits.

Thermal energy consumption can also be reduced by adopting latest technology coolers (third generation) which operate with cooler loss of less than 100 kcal / kg clinker through cooler vent, clinker and radiation loss. Typical second generation coolers available in majority of the plants operate with total cooler loss of 130 to 150 kcal / kg clinker. Hence, adopting the latest technology can result in direct thermal saving of 30 to 50 kcal / kg clinker. Another opportunity available is adopting latest burners which have lower percentage of primary air increasing the combustion efficiency. Oxygen enrichment, recirculation of cooling air are other thermal energy reduction opportunities under development.

Significant portion of energy consumed in the cement manufacturing process is in handling the variety of materials having different shapes and properties (abrasiveness, moisture content, flowability) in different sections such as mining, raw material preparation, clinkerisation, materialstorage, cement grinding and packing. Proper layout design, equipment selection and automationcan help in lowering the energy consumption.

Other utilities that need focused attention are compressors, water pumps, cooling and air conditioning, and Heating ventilation and air-conditioning (HVAC) systems. Some of the latest developments in the utility area are high efficiency pumps, energy efficient centrifugal and screw blowers (that can reduce 30-50% of energy consumption compared with conventional old generation positive displacement blowers over a wide range of operations) high efficiency motors, energy efficient lighting such as LED, magnetic induction and metal halide lamps.

To meet the power demand (considering power shortages and supply demand gap) and to reduce energy cost, captive power generation has become integral part of cement manufacturing in India.

While some of the captive power plants in the country are operating as low as Auxiliary power consumption (APC) of 5% and heat rate of 2800 kcal / kWh, the gap between the best and the national sectoral average indicates significant saving potential opportunity. Installing variable speed drives in water and flue gas circuit, optimizing turbine efficiency, maintaining Plant Load Factor, optimising combustion efficiency through advanced control systems and power conservation in auxiliary circuits like coal handling and ash handling are the levers available in captive power plants.

As estimated in the Technology Roadmap, efficiency is expected to remain relatively constant in the 6DS, i.e. 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 scenario in 2050. Electrical efficiency will improve from 80 kWh/t cement in 2010to between 78 kWh and 72 kWh/t cement in 2050. The higher improvements in the High- Demand

Case are due to the higher share of new plants compared to the Low-Demand Case.

However, in 2DS, specific energy consumption would reduce to 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 CO2emissions savings of about 25 million tonnes CO2 in 2050.

Broadly, increased use of AFR as envisaged above, is expected to result in increase in specific energy consumption primarily because of higher air requirement and higher moisture levels.

However, the overall lower CO2 emissions through increased use of alternative fuels outweigh the disadvantage of increased specific energy consumption. On the R&D aspects, adoption of fuel cells to meet the power requirement of cement manufacture along with large-scale dissemination of certain futuristic comminution technologies and scale up and commercialization of low carbon cement such as celite cement, geopolymers, etc. offer significant energy reduction opportunities.

However, since these are still only viable at laboratory scale, a major thrust in R&D is required toadvance to pilot and demonstration scales, and then to wide spread implementation.

At this juncture, it would not be out of place to address CO2 emissions from Captive Power Plant (CPP)'s operating as integral component of cement plants. About 60% of the electricity used in cement plants today is from CPPs, which have an average CO2 emission factor of 1.2 kgCO2/kWh of electricity produced with auxiliary power consumption ranging from 10-13%.

Therefore, improved energy efficiency coupled with power generation through low or zero emission technologies, can substantially reduce CO2 emissions from CPPs. Assuming that CPPs will continue to account for around 60% of cement electricity requirements, between 80 million tonnes CO2 and 150 million tonnes CO2 could be saved in 2050.

Reduction in clinker factor

Third lever is the further reduction in clinker factor. In line with Indian cement industry, major plants of Rajasthan has been gradually increasing the share of blended cement in its overall cement mix.

The potential to reduce the clinker-to-cement ratio depends greatly on the availability of alternative materials. Under a 2DS, in which the power sector is virtually decarbonizes, 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 granulated blast furnace slag (GBFS) and other blending material from non-ferrous industries may increase considerably. Several different clinker substitutes can potentially be used in cement, and their relative merits and availability are presented in Table 2.

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.

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, the latter of which would have a strong impact on the energy consumption and CO2 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 MtCO2 and 150 MtCO2 (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.

Scale up and commercialization of potential futuristic technologies

The fourth major lever and probably the most impactful one is scale up and commercialization of potential futuristic technologies such as use of mineralizes, fluidized-bed advanced cement kiln system (FAKS), carbon capture and carbon use for algal growth for biofuels production, geopolymer cement, use of nanotechnology in cement production, etc.

Use of mineralizes to improve burnability of the raw mix

Mineralizes added to raw materials entering the kiln can reduce the clinkerisation temperature byabout 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 mineralizes is generally determined by considerations such as reaction effects desired, compatibility with a given kiln's raw materials, the specific process adopted, physical form of the mineralizes and economic viability of using mineralizes.

Fluidized-bed advanced cement kiln system (FAKS)

The fluidized 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 CO2 levels in the growing environment; the necessary photosynthesis can be stimulated in either open ponds or close 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 CO2 needed could be provided either directly from the kiln flue gases or in a more pure formvia a CO2 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 dimension alinorganicaluminosilicate 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. Nanocementproduction allows for the use of larger quantities of mineral additives, and therefore havethe potential to provide significant savings of cement and lower CO2 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 nanosilica,in cement mortar and concrete. Potential health hazards associated with the handling anduse of nano-particles need to be studied, understood and mitigated

Carbon capture and storage (CCS)

Among the newer technologies for CO2 emissions reduction presented in this roadmap, only CCSis considered to become commercially available over the timeframe analysed. CO2 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 MtCO2 and 171 MtCO2 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- pipemechanisms – will not require fundamental changes in the clinker-burning process, and could beretrofitted 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 CO2 flue gas,has been shown to improve cement production efficiency without markedly increasing the fuelconsumption 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 capturetechniques, the cost of oxygen gas production is high. Moreover, significant re-engineering of the plant may be needed to accommodate altered thermodynamics and material stress of operation inan oxygen-rich environment. Concerted R&D into oxy-combustion is warranted to better understand any impacts on product quality.

Increased adoption of WHR systems

An additional major lever available to the Indian cement industry is increased adoption of WHR systems in manufacturing facilities. This uptake has been relatively slow compared to other countries mainly because of layout constraints coupled with high initial costs. 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 isonly 110 MW. Therefore, opportunity exists for adopting WHR in Indian cement industry. 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, dependingon 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 costcement 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.

Policy initiatives and interventions required

In the absence of appropriate technological/policy measures, CO_2 emissions from the Indian cement industry are projected to reach 488 Mt CO_2 (low demand scenario) and 835 Mt CO_2 (high demand scenario) by 2050. With the technologies, policy framework and investment needs outlined in roadmap, these emissions could be limited to 75 Mt CO_2 (low demand) and 468 Mt CO_2 (high demand). Achieving these milestones would enhance energy security by saving 377 PJto 485 PJ energy by 2050. Various policy initiatives are proposed in the roadmap, as below: The technical aspects of AFR use are well tested and proven, with extensive evidence documenting emissions, and the process with which to collect, handle and use AFR in a cement kiln. However, the Indian cement industry has limited experience of AFR use in its kilns, because implementation across the country is very low. Wherever AFR has been used in Indian cement kilns is predominantly biomass (up to 10-12% TSR), and not municipal or industrial waste. For target thermal substitution levels of 30%, specific thermal energy may increase by 0-40kCal/kgclinker depending on the type of system and fuel. Policy interventions required to increase AFRuse are: to increase the availability of sorted waste and low calorific value of municipal waste; to enable the trans-boundary movement of hazardous waste across state boundaries; to ensure legislation encourages co-processing in the cement industry, and to reduce complicated procedural systems for co-processing; to ensure land availability to install pre- processing facilities.

The Indian cement industry already has one of the highest efficiencies in the world, yet further super efficiency can be achieved in some areas. India's environmental norms, necessitating the installation of additional equipment, may increase future energy consumption at a plant level, so any policy changes, and trade-offs around other issues, must be carefully considered before implementation. Barriers to higher efficiencies are a low grid power quality, and uncertainty around the price of Certified Emission Reductions (CERs) and Energy Saving Certificates (ESCerts) within the PAT scheme.

Increased blending rates in the Indian cement industry would decrease carbon emissions because less CO_2 emissions would be required per tonne of cement produced. However, various barriersexist that limit blending rates in India: fly ash is sold through competitive bidding making PPC manufacturing financially unviable in many locations; existing standards/codes need to be modified, and new codes developed, to ensure uptake of composite and blended cement; consumer awareness on the quality of blended products and confidence of builders to use these cements needs to be increased, as well as anomalies in fly ash utilization policy ironed out. One potential policy change that would incentivize increased blending rates would be a mandatory requirement to give 20% CPP fly ash to brick vendors.

Extensive efforts need to be made to implement new technologies, bringing them to pilot, demonstration and full-scale implementation as soon as possible. Many such technologies are inconceptual, R&D and pilot plant stages only, and some which are available at scale are patentedand not available in the open market. Long-term investments need to be made in the number andskills level of scientific researchers with cement industry expertise by creating teaching andresearch positions on materials science. Government policy must incentivize and facilitatetechnology transfer, and financial and infrastructural support must be provided for domestic R&Dactivities, to ensure India's R&D is among the most advanced in the world in bringing new andpotential technologies to scale.

State 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. Providing renewable energy status for WHR systems, and ensuring certainty around WHR within Clean Development Mechanism (CMD) qualification would support its uptake in Indian cement plants. Duty incentives for the import of WHR equipment / technology would further increase utilization.

Research and development needs Research and development needs for AFR

Increased alternative fuel substitution is one of the most promising solutions for handling the environmental problems associated with different types of waste (especially MSW) generated in the country.

High levels of substitution is well established and very common in many of the European countries. However, due to significant difference in nature and characteristics (material type, organic content, high moisture, difference in climate zones) of waste generated in India, further R& D is needed in material handling equipment (collection, segregation and feeding systems) to customize them for Indian conditions for increasing utilization.

R & D is also needed to suggest the best environmental option in the waste management hierarchy for handling different types of wastes generated according to local conditions by conducting LCA studies with country specific data sets, social, economic impacts and existing pollution control measures.

Specific national Missions of the Government of India can be promoted to create awareness among policy makers and municipalities, build capacity through training and sharing of best practices, encourage technology transfer, nurture indigenous service providers for waste pre processing, transportation and usage including environment control measures, and implement policies to simplify procedures for usage.

Research and development needs for increasing thermal/electrical energy efficiency

Significant indigenous R & D measures are needed to further improve the efficiencies of equipment such as mills, fans, material handling equipment, utilities and captive power plants. Capacity building in energy efficiency and conservation measures specific to cement industry is another prime area of concern considering the demand for qualified and competent professionals in view of the higher growth rate of the sector.

Research and development needs for reducing clinker factor

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.

Research and development needs for futuristic technologies

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 toensuringcountryspecific,cost-effective and technically viable options for emissions reduction.

Research and development needs for WHR

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.

Conclusions

The Indian cement industry has already reduced CO_2 emissions intensity from 1,120 kg/tonne cement in 1996 to 719 kg/tonne cement in 2010. In the absence of appropriate technological and policy measures, CO_2 emissions are projected to reach 488 Mt CO_2 (low demand scenario) and 835 Mt CO_2 (high demand scenario). However, with continued concerted efforts, and conducive policy and financial frameworks, the industry could limit CO_2 emissions to 275 Mt CO_2 (low demand) and 468 Mt CO_2 (high demand).

An estimated $29 billion of additional investment is expected to be required to reach these goals, and innovative funding mechanisms need to be developed to support this. Nearly half of this figure would be required to fund R&D and new/upcoming technologies.
These investments will need to be supported by adequate policy interventions and require extensive dialogue between industry, regulatory and policy making bodies, trade associations and equipment/technology providers.

References

[1] Bureau of Energy Efficiency, Cement Sector Expert Committee meeting, September 2011.
[2] Centre of Science and Environment (2010) Challenge of the new balance: a study of the six most emissions intensive sectors to determine India's low carbon growth options, Delhi
[3] Confederation of Indian Industry (CII) Sohrabji – Godrej Green Business Centre Low carbon roadmap for Indian cement industry (2010), Hyderabad.
[4] European Cement Research Academy (ECRA) (2012) Technical papers for the Indian cement industry - looking behind the data, ECRA-CSI, Duesseldorf.
[5] ECRA (2009), Development of State of the Art Techniques in Cement Manufacturing: Trying to Look Ahead, ECRA-CSI, Duesseldorf. Government of India Planning Commission Interim report of the expert group on low carbon strategies for inclusive growth (2011), Delhi.
[6] European Union Directive 2000/76/EC of the European Parliament and of the Council of 4 December 2000 on the incineration of waste (2000), Brussels.
[7] EU, The Reference Document on Best Available Techniques in the. Cement, Lime and Magnesium Oxide Manufacturing Industries (2010), Brussels.
[8] Government of India (GoI) (2011) Interim report of the expert group on low carbon strategies for inclusive growth, Planning Commission, Government of India.
[9] 'Cement Technology Roadmap 2009', (WBCSD, IEA, 2009)
[10] 'Low Carbon Strategies for Inclusive Growth: An Interim Report' (Planning Commission,
[11] Government of India, May 2011)
[12] 'Scenarios and projections', http://www.iea.org/publications/scenariosandprojections/ (IEA, accessed May 2013)
[13] 'Technology papers for the Indian cement industry - looking behind the data' (ECRA, August, 2012)
[14] 'Technology Roadmap: Low carbon technology for the Indian Cement Industry' (WBCSD, IEA,
[15] February 2013)