Low Carbon Technology Roadmap for the Indian Cement Sector: Status Review 2018

Contents

Foreword

The cement industry lies at the intersection of two global megatrends. Infrastructure advancements that will improve the lives of billions will fuel massive demand, while regulatory pressures and the need for sustainability-driven business strategies aligned with climate agreements will pose new and unique product and leadership challenges.

Rapid urbanization and industrialization are currently fueling exponential market demand for cement globally; it is expected to reach over USD $725 billion by 2025, expanding at a compound annual growth rate (CAGR) of 7.3% from 2017 to 2025.[i] India, the second largest producer of cement in the world, is experiencing a similar wave of dynamic growth as an outcome of rising consumer demand, inflow of foreign direct investments (FDI), oligopoly market conditions and affirmative policy instruments. As of 2017, the sector reported production capacity of 410 million tonnes (Mt), which is expected to reach around 600 Mt by 2025.[ii]

One of the key drivers of this extensive growth in the Indian cement industry is the holistic approach the sector is taking to follow a low-carbon pathway. By adopting state-of-the-art technological interventions, innovative production techniques and climate-resilient resource optimization measures, cement manufacturers in India are integrating sustainability within their growth aspirations. The sector has already surpassed the targets of the Perform Achieve and Trade (PAT) scheme by 80%[iii] and is now being recognized globally as one of the most energy-efficient and sustainable markets for cement.

The sector first embarked on this transformative journey nearly a decade ago. In 2009, the World Business Council for Sustainable Development's (WBCSD's) Cement Sustainability Initiative (CSI) member companies, in collaboration with the International Energy Agency (IEA), developed the first-ever roadmap by any industry to identify and implement technologies to reduce cement production energy use and carbon intensity. This global roadmap outlines emissions reduction potential from all technologies that companies in the cement industry can potentially implement.

Building on the success of the global roadmap, the CSI and IEA, in collaboration with the Confederation of Indian Industry (CII) and the National Council for Cement and Building Materials (NCB) and with partial funding support from International Finance Corporation (IFC), jointly developed a roadmap specifically for the Indian cement industry in 2013. The Low-Carbon Technology Roadmap (LCTR) for India is aimed at building a transition path for the cement industry to support the global goal of halving carbon dioxide CO_2 emissions by 2050. The projections in this roadmap show that the Indian cement industry would reduce its direct CO_2 emissions intensity to 0.35 tonnes (t) of CO_2 per tonne of cement in 2050, about 45% lower than 2010 levels, a savings of between 212 million tonnes of CO_2 ($MtCO_2$) and 367 $MtCO_2$ in 2050 compared to a business-as-usual scenario.[iv]

Five years after the launch of the LCTR, CSI in India members have conducted a comprehensive study on the sector's performance trends, significant implementation measures and achievements based on the milestones set in the roadmap. This status review provides stakeholders with the data on progress so far and an indication of how the low-carbon future of the Indian cement sector will evolve.

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Key findings

The Indian cement industry is recognized globally as one of the most energy efficient in the world, with relatively large production units and the use of low-carbon, cost-effective technologies. Almost 99% of the installed capacity in India uses dry process manufacturing, of which 50% has been built in the last 10 years.

While installed capacity grew rapidly over the past seven years[1] (2010-17), cement production in the country has witnessed a more steady increase, from 217 Mt (2010) to 280 Mt (2017).

The direct CO_2 emission intensity[2] ($kgCO_2$/t cement) has gone down by 32 $kgCO_2$/t cement to 588 $kgCO_2$/t cement in 2017 – a 5% reduction as compared to the baseline year of 2010. The sector has achieved the 2020 performance objective for emissions intensity reduction three years ahead of schedule. The reduction is mainly due to increases in alternative fuel use, reductions in clinker factor and increases in blended cement production. The sector will need to make significant efforts to achieve the 40% reduction required to meet the 2050 objectives.

The CO_2 emissions intensity (including onsite/captive power plant (CPP) power generation) has gone down by 49 $kgCO_2$/t cement to 670 $kgCO_2$/t cement in 2017 compared to the baseline year - a 6.8% reduction.

Indian cement plants' adoption of waste heat recovery systems (WHRS) has offered numerous benefits, such as mitigating greenhouse gas (GHG) emissions and achieving PAT cycle targets. WHRS capacity in India increased by 212% in 2017 compared to 2010, with total installed capacity of 344 MW in 2017. This may ultimately help contribute to long-term energy security in India.

Alternative fuel use, i.e., the thermal substitution rate (TSR), increased from 0.6% in 2010 to 3% in 2017.

More than 60 cement plants in India have reported continual use of alternative fuels. 24% of the total alternative fuels consumed is biomass.

The share of blended cement in the total quantity of cement manufactured in India in 2010 was 68%. This increased to 73% of total cement production in 2017, largely due to the market's growing acceptance of blended cement, emerging awareness of sustainability concepts, the availability of fly ash from thermal power plants and the use of advanced technology. The production of Pozzolana Portland cement (PPC) grew from 61% in 2010 to 65% in 2017. The share of Portland slag cement (PSC) in cement production remained flat, at less than 10%, over the same period. The clinker factor improved from 0.74 in 2010 to 0.71 in 2017.

India's cement industry has shown an ability to invest and reduce CO_2 emissions. This ability will be helpful in achieving a low-carbon future.

A lack of advances in new technologies to reduce process emissions and of economically feasible and scalable models for carbon capture, storage and use could act as impediments for the sector to achieve the science-based reduction goals laid out in the LCTR. However, the industry continues to deploy a combination of policy and technology options to support a low-carbon transition path.

From improving energy consumption patterns during the production process to increased use of alternative fuels by recovering energy from a range of waste streams, the Indian cement industry is gradually positioning itself to be at the heart of a circular economy.

[1] Data for 2010 presented in the report is for financial year 2009/10 ending 31 March 2010; the same is true for 2015, 2016 and 2017.

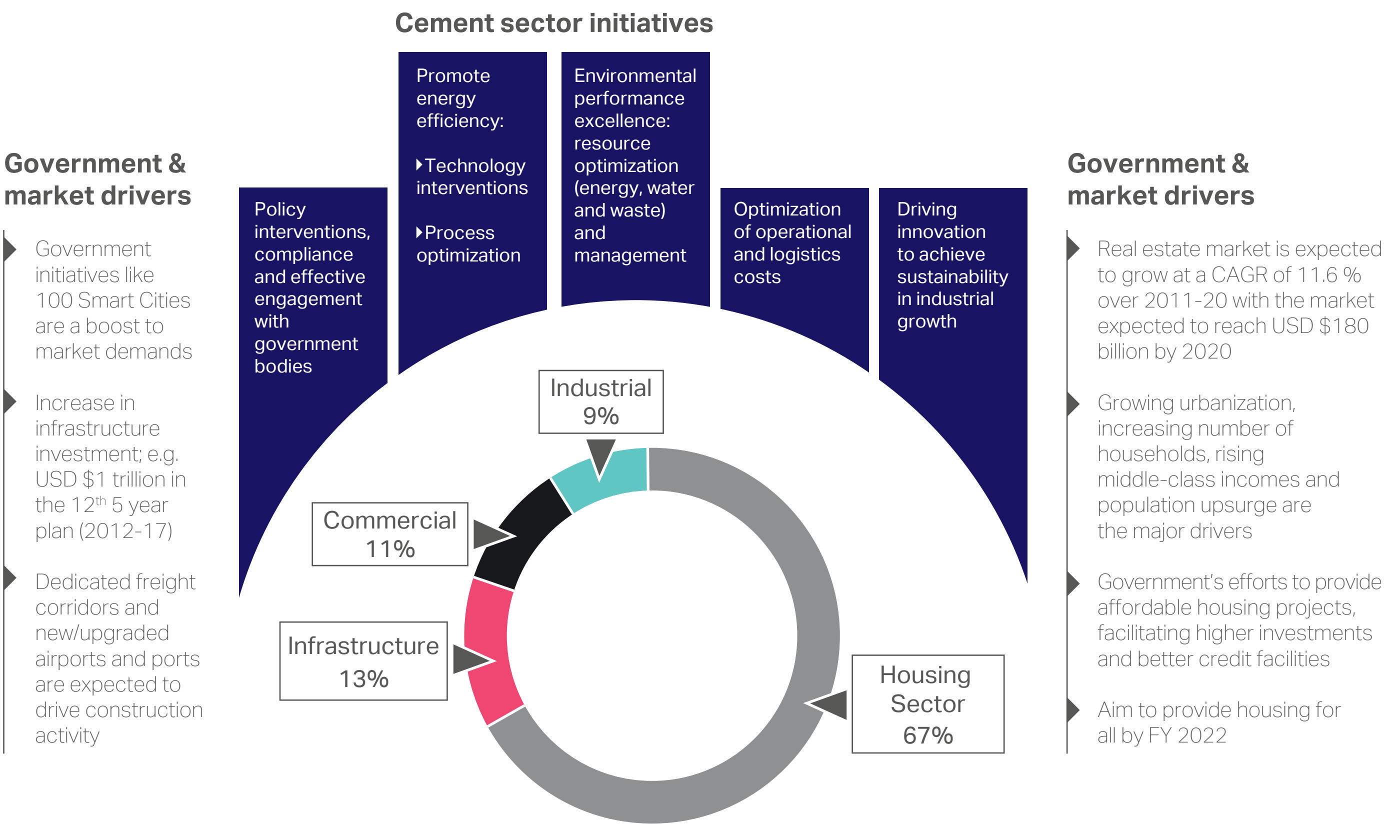
[2] Includes only direct emissions from cement manufacturing; we did not consider indirect emissions from electricity use.

Evolving landscape and transition to a low-carbon future

Over the past seven years, cement production in India has increased steadily, from 217 Mt in 2010 to 280 Mt in 2017, on the back of the country's urbanization and industrialization. This in turn has also contributed significantly to India's economic growth. The country's cement production is projected to increase at a CAGR of 6-7% by 2025 due to increasing demand for housing and commercial real estate and the government's focus on infrastructure development. The industry is currently producing 280 Mt to cater to domestic demand, with per capita consumption standing at around 195 kg.[v] This is far below the world average of 520 kg/capita,[vi] which means there is a significant business opportunity to cater to unmet demand in the future.

By deploying dry manufacturing processes coupled with energy-efficient technologies, the industry has been progressively meeting electrical and thermal energy reduction targets. The use of alternative raw materials such as fly ash and slag, the enhanced use of renewable energy and the adoption of waste heat recovery systems are where the sector has made the largest gains.

Figure 1: Major growth drivers for the Indian cement industry



Revisiting the context – Low-Carbon Technology Roadmap 2013 objectives

The collaboration to develop the Low-Carbon Technology Roadmap (LCTR) for the Indian cement industry stemmed from the previous joint effort by the World Business Council for Sustainable Development (WBCSD) and International Energy Agency (IEA) to publish the global Cement Technology Roadmap 2009.[vii]

The global roadmap outlines four key levers – and the necessary policy and financial support – to reduce CO_2 emissions within the cement manufacturing process. Understanding the potential of such a roadmap to identify and trigger emissions reductions up to 2050 and the unique challenges and opportunities that exist in India, WBCSD Cement Sustainability Initiative (CSI) project members in India partnered with the IEA in 2013 to set out a roadmap specifically for India. The International Finance Corporation (IFC) provided technical support and partial funding.

The LCTR 2013 aims to identify technologies, especially those with relevance to India, supportive policy frameworks and investment needs that could lead to direct emissions reductions of about 0.28 tonnes (t) of CO_2 per tonne of cement produced, i.e., from 0.62 tCO_2/t cement in 2010 to 0.35 tCO_2/t cement in 2050. Such a reduction in emissions intensity would limit CO_2 emissions growth from the cement industry to between 100% and 240% compared to the current level.

The LCTR 2013 also outlines an action plan for specific stakeholders to show the short- and longer-term priorities to reach such emissions reductions. 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 carbon-intensive energy sources, decreasing the clinker-to-cement ratio and applying new technologies.

Tracking progress

This Status Review gauges the current status of the Indian cement industry vis-à-vis the trajectory outlined in the LCTR 2013. We provide a critical analysis of the various performance trends, sectoral barriers and dynamics reported in the first five years following release of the LCTR. The scope of this study encompasses a range of indicators that ascertain cement company reductions in carbon emissions using technological interventions and innovative practices.

The study tracks performance trends and the good practices adopted by the sector for five emissions reduction levers: thermal and electrical energy efficiency; waste heat recovery systems (WHRS); alternative fuels and raw materials (AFR); clinker substitution; and newer technologies (such as the use of mineralizers, geopolymer cement, carbon capture and use for algal growth for biofuel production, etc.). We show a comparison in terms of levers between the target and the achieved value and identify the key factors for the deviations between the expected and the achieved results within individual levers.

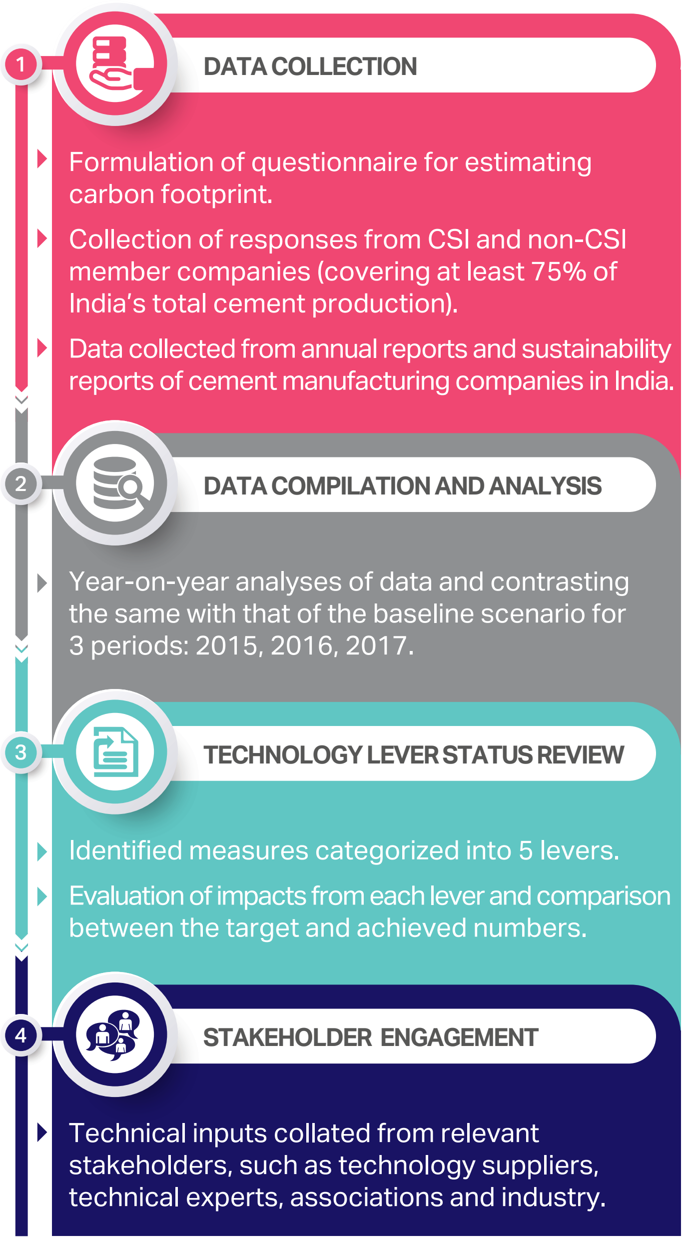
The study is based on parameters including production trends, product mix, clinker factor, specific energy consumption (both electrical and thermal), fuel consumption, AFR consumption (thermal substitution rate – TSR), WHRS installation, renewable energy integration and reductions in greenhouse gas (GHG) emissions intensity. We have analyzed these parameters over a three-year period, from 2015-2017, and drawn up a comparative analysis with the 2010 baseline data. In order to substantiate the analyses, we have sourced the data from various CSI and non-CSI member companies whose total cement production amounts to 75% of India's cement production.

To further complement the analysis in the study, we have identified various technologies that have been implemented for each of the levers, not only to evaluate each one's impact on emission reductions, but also to identify those aspects of specific thermal and electrical energy reductions that lead to cost savings.

In addition to the above, the study also looks at:

- **Sectoral benchmarks:** developing sectoral benchmarks based on best practices adopted by companies for each of the technology levers – specific thermal and electrical energy consumption, AFR use, clinker factor and GHG emissions.
- **Estimating the scalability and impact potential:** identifying the scalability potential of the technologies highlighted in the LCTR and assessing the impact of carbon emissions reductions (including GHG benefits) for technical levers.
- **Status of barriers:** identifying various challenges and barriers to accelerate the implementation of technologies, from technical, financial or policy perspectives.
- **Financial requirements:** evaluating the financial requirements and carbon emissions reduction potential of the sector in implementing various technologies.
- **Policy interventions:** deliberating policy-level interventions to accelerate the use of low-carbon technologies.

Figure 2: Status review approach



Carbon emissions reduction levers: snapshot of progress

Goal 13 of the United Nations 2030 Agenda for Sustainable Development, which world leaders adopted in September 2015, calls for urgent action to combat climate change and its impact. The Paris Agreement, negotiated in December 2015 at the 21st session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC), attempts to limit the rise in global temperatures in this century to less than 2°C above preindustrial levels.

The cement industry currently represents about 7% of CO_2 emissions globally and is the third-largest industrial energy consumer.

Given this background and the growing need to safeguard the future, the Indian Cement Industry has been taking proactive measures to carve out a low-carbon pathway for the sector, under the aegis of the 2013 Low-Carbon Technology Roadmap (LCTR) for the Indian cement sector.

Since 2010, CSI members in India have been acting to reduce CO_2 and voluntarily report independently verified CO_2 and energy performance information to the Getting the Numbers Right (GNR) database.

As part of this status review, we have analyzed the changes in carbon emission intensity and the contributions from different levers. The direct CO_2 emissions intensity (kgCO_2/t cement) has gone down by 32 kgCO_2/t cement to 588 kg CO_2/t cement in 2017 as compared to the baseline year (2010). The reduction of 5% is mainly due to increases in alternative fuel use, reductions in clinker factor and increases in blended cement production. With this reduction, the sector has already achieved the objectives for 2020 as projected in the LCTR. The sector will need to make significant efforts to reach the additional 40% reduction required to meet the 2050 objectives.

Figure 3: **Direct CO_2 emission intensity (kgCO_2/t cement)**

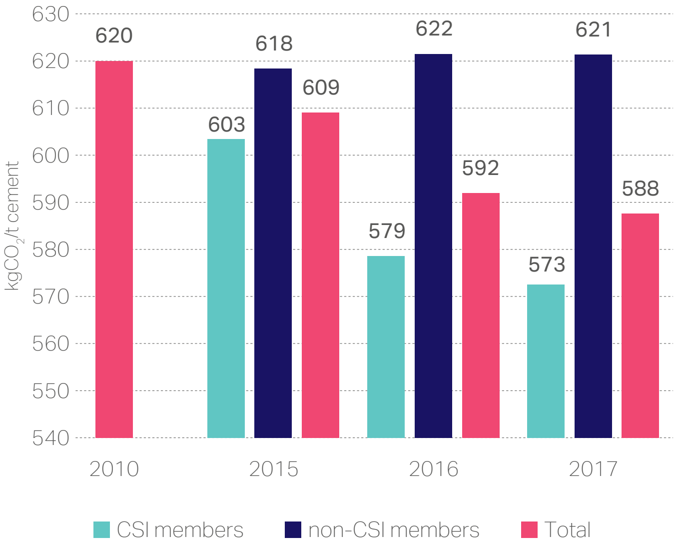


Table 1: **Contribution of different levers to emission intensity reduction***

Lever	Emission intensity contribution (kgCO_2/t of cement)
Thermal energy efficiency	+5.33
Clinker substitution	-33.3
Alternative fuel use	-4.39
Net reduction	-32.4

** There is a reduction of 0.44 kgCO_2/t of cement due to renewable power and 5.9 kgCO_2/t of cement due to WHRS improvements compared to the baseline year. However, both are not considered in direct emissions intensity reduction due to the exclusion of electrical energy.*

Installed capacity and production potential

The cement sector in India has reported its total installed capacity for cement production as of 2017 as 410 Mt, an increase of more than 100 Mt (+33%) since the baseline year of 2010.

Rising demand from the housing and infrastructure sectors is behind this year-on-year increase in production. Installed capacity of CSI members increased from 131 Mt in 2010 to 236 Mt in 2017. Drivers of this increase in capacity include various factors, such as CSI member company investments in greenfield projects and the acquisition of new plants.[3]

Total cement production increased from 217 Mt in 2010 (capacity utilization of 72%) to 280 Mt in 2017 (capacity utilization of 68%). CSI member companies accounted for almost 52% of total cement production in the country in 2017.

Cement capacity utilization potential has also witnessed a significant change compared to the baseline scenario. For CSI members, capacity utilization was around 71% in 2010. This decreased to 62% in 2017. For non-CSI member companies, capacity utilization was around 73% in 2010, which increased to 77% in 2017.

Figure 4: Cement installed capacity and actual production (million tonnes per annum – MTPA)

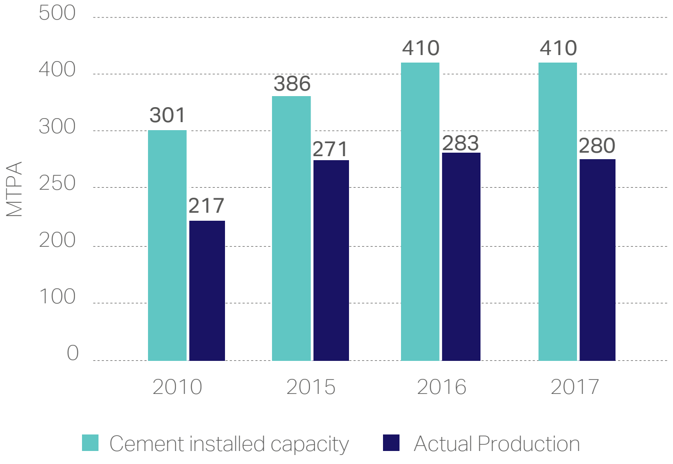
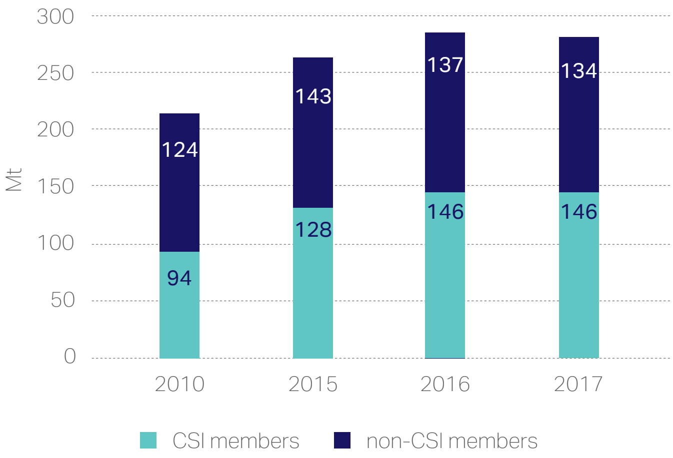


Figure 5: Cement production (million tonnes)



Key changes in carbon reduction levers over five years

In this Status Review, we infer certain trends based on the information compiled and comparative analyses of year-on-year performance data with the baseline scenario. We have observed an emerging trend for each of the technology-enabled carbon reduction levers. We discuss the causal factors, challenges, requirements and futuristic approaches for each of these emerging trends in the subsequent sections.

[3] WBCSD CSI welcomed two new member companies during the reporting period.

We compared the performance witnessed over a three-year period (2015-2017) for each lever to the expected levels outlined in the LCTR 2013.

Figure 6: Overview of lever-wise performance

Lever 1: electrical & thermal energy efficiency

Context

The Indian cement industry has been growing rapidly since the late 20th century. When building new cement plants, manufacturers have installed the latest energy-efficient technologies by design. As a result, recent cement plants have achieved high levels of energy-efficiency performance. As electricity tariffs for industry in India are among the highest in the world, implementing such energy-efficiency measures at the design stage provides cement manufacturers with significant advantages by lowering energy and production costs. Increasing energy costs have also prompted owners of older manufacturing facilities to gradually adopt the latest energy-efficient technologies and improve their energy performance.

The industry has reduced its overall specific electrical energy consumption (SEC – Electricity), in cement production from 80 kilowatt hour/tonne of cement (kWh/t cement) in 2010 to 76 kWh/t cement in 2017. The steady increase in the production of blended cement (72%) in 2016 and 2017 and improvements in the clinker factor have mostly driven this reduction. A decrease in clinker quantity in cement implies lower energy consumption for grinding. Despite increased use of petcoke and alternative fuels, frequent stop-starts due to market conditions and low capacity utilization, the specific electrical energy use of clinkerization (kWh/t clinker) decreased by nearly 1 kWh/t clinker compared to the baseline (2010).

Figure 7: SEC – Electricity

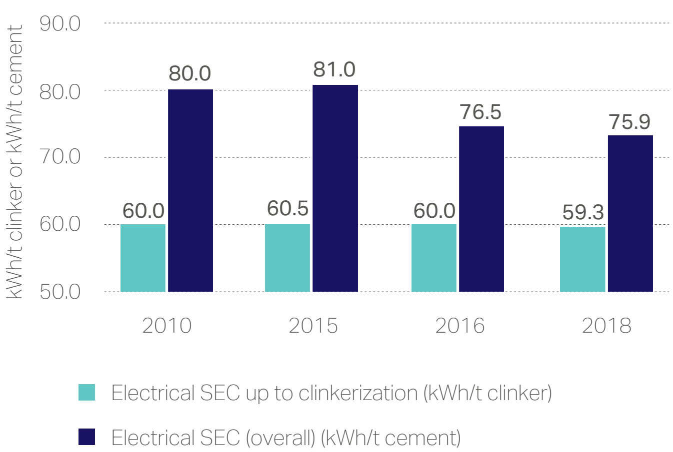


Figure 8: SEC – Electricity, up to clinkerization (kWh/t clinker)

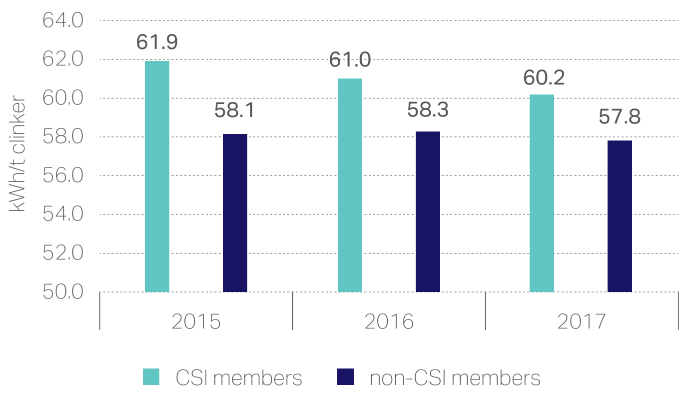
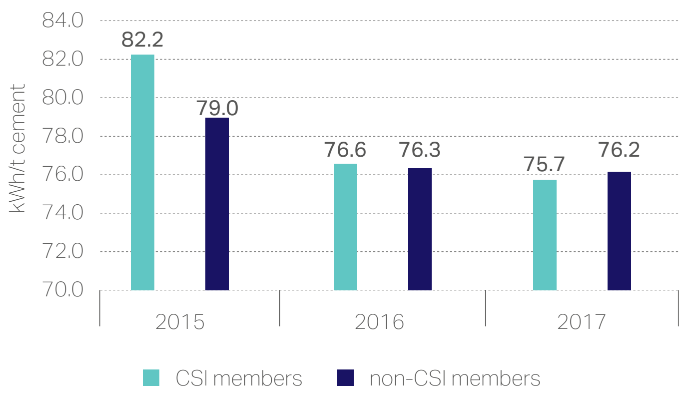


Figure 9: SEC – Electricity, overall (kWh/t of cement)



The thermal SEC increased to 744 kcal/kg clinker in 2017 compared to 725 kcal/kg clinker in 2010. The increase in thermal SEC can be attributed to increased petcoke use, increases in alternative fuel use and frequent start/stops due to low market demand.

Figure 10: **SEC – Thermal, overall average (kcal/kg clinker)**

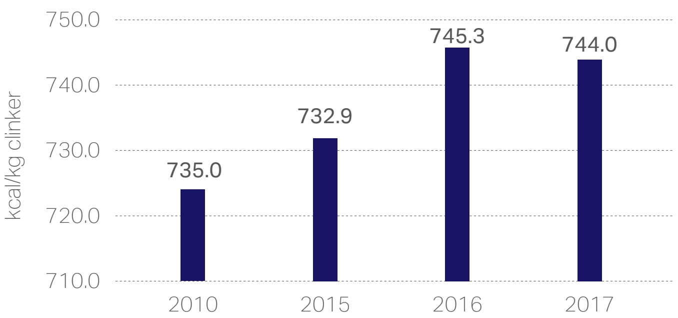
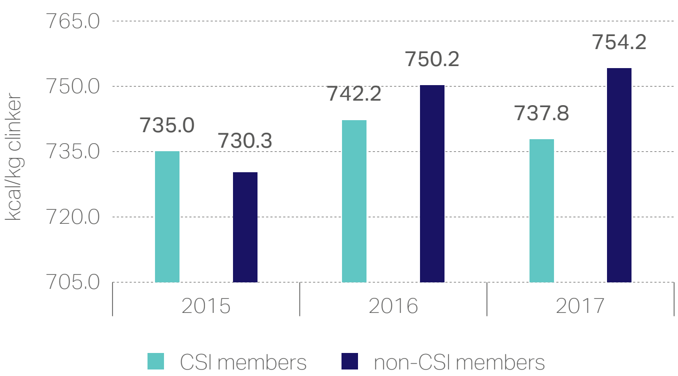


Figure 11: **SEC – Thermal (kcal/kg clinker)**



Market changes and improvements observed

From 2010-2017, we have observed the following sectoral dynamics with respect to electrical and thermal energy-efficiency improvements.

Preheater and kilns: companies made a number of improvements in preheaters and kilns, such as the installation of platforms and alternative fuel feeding systems, nitrogen oxides (NOx) control systems, waste heat recovery from kiln shell radiation, energy-efficient blowers for kiln and calciner coal feeding systems and optimizing phase density, the pre-mixing of fuel and raw meal to improve heat transfer and reduce NOx, and modifications in cyclones based on computational fluid dynamics (CFD). The installation of alternative fuel feeding systems and NOx control systems results in increases in SEC.

Latest generation high-efficiency clinker coolers: improvements include the installation of high-efficiency clinker coolers by certain plants, recirculation systems to maximize cooler recuperation efficiency and excess power generation through WHRS installed on the cooler side, heat shields to improve cooler recuperation efficiency and the installation of latest generation efficient cooler grates.

Grinding systems: improvements include secondary classification in the grid cone, the use of CFD to improve classification efficiency, multi-drive systems, vibration-based sensors for filling control, the adoption of high-pressure grinding rollers (HPGR) instead of vertical roller mills (VRM) for slag and cement grinding, the optimization of air flow by providing angular flow channels below rollers, and the installation of latest generation classifiers.

Process fans: the major improvements observed are the installation of high-efficiency fans, preheater systems with fan SEC as low as 4 kWh/t clinker, and the use of slide gates instead of dampers for major fans with variable frequency drives (VFD).

Auxiliary equipment: auxiliary equipment such as vertical conveyors, tri-lobe blowers, three-phase transformers for increased collection efficiency in electrostatic precipitators, lower head pumps to cool water circuits with booster pumps for specific application, aluminum piping to reduce the pressure drop, water-cooled condenser coils for packaged air conditioning and the installation of screw chillers instead of compression chillers.

Policy driver: Perform, Achieve and Trade (PAT) scheme

The Indian government announced PAT, an innovative, market-based trading scheme, in 2008 under its National Mission on Enhanced Energy Efficiency (NMEEE) in the National Action Plan on Climate Change (NAPCC). PAT aims to improve energy efficiency in industries by trading in energy-efficiency certificates in energy-intensive sectors.

Under the PAT scheme, designated consumers (DCs) are assigned targets for reducing their specific energy consumption. The target reduction for each DC is based on its energy-efficiency quotient during the baseline year (2010), such that energy-efficient DCs have a lower percentage reduction target compared to those that are less energy efficient.

The first PAT cycle period ran from 2012 to 2015 and included 85 cement plants. The target allocated to these plants was to reduce energy consumption by 0.815 million tonnes of oil equivalent (MTOE). The plants in PAT cycle 1 surpassed the energy saving targets and achieved savings of 1.48 MTOE, which is around 81% higher than the savings target.[viii]

Under the PAT scheme, energy from alternative fuels is accounted for as zero. During PAT cycle 1, the most significant contributions were from the use of alternative fuels and waste heat recovery.

PAT has further enhanced energy efficiency in the cement sector and, as a result, the sector is currently among the best globally. Some of the key measures that cement manufacturers have taken in India to achieve their PAT targets include: the installation of co-processing platforms and pre-processing systems to feed-in alternative fuels, resulting in reductions in carbon emissions; and the upgrading of conventional clinker cooler systems with latest generation ones.

Figure 12: **Savings achieved by the cement sector in PAT cycle 1**

Energy savings:
1.48 MTOE

Coal saved:
3.42 million tonnes

GHG reduction:
4.34 $MtCO_2$ equivalent

Savings:
INR 16 billion

Reported investment:
INR 26 billion

Source: Bureau of Energy Efficiency, GIZ & Confederation of Indian Industry. 2018. Improving energy efficiency in the cement sector.

PAT cycle 2 will cover 111 cement plants. The average reduction target for the sector in cycle 2 remains similar to that in cycle 1 (4-5%). It will be challenging for the sector to achieve these targets since most of the easy changes have already been made.

The appropriate pricing of Energy Saving Certificates (ESCerts) is crucial to ensuring the continued effectiveness of the PAT scheme.

Challenges to implementation

Over the last seven years (2010-2017, Indian cement companies reported several technical, financial and regulatory barriers to the adoption of technological advancements to improve electrical and thermal energy efficiency. Factors such as layout constraints, high moisture content in limestone and the burnability index of raw mix pose technical barriers for preheaters and kilns.

One of the major limitations in the installation of high-efficiency clinker coolers is the uncertainty around estimating the guaranteed benefits for retrofit installations. Additional shutdown time requirements for retrofits is another. In financial terms, incremental costs for new installations and overall costs for retrofit installations are also a challenge.

In terms of technology, there are still a few challenges, such as the capacity limitations of a roller press, whereas possibilities of higher efficiencies are by voltage regulator module. Retrofitting costs to upgrade grinding technology are very high and have long payback periods, i.e., 6 -10 years (if only energy savings are considered).

Challenges associated with retrofitting uniflow burners with advanced multi-channel burners include high costs and long payback periods. We have observed that many plants have installed the latest energy-efficient burners, which have shown good reductions in NOx generation and primary air consumption as low as 3.5%.

In terms of energy-efficiency improvements in process fans, a few technical challenges are associated with layout in facilities where the ideal duct system cannot be accommodated. Moreover, the cost of retrofitting in certain cases could be high. Higher investment and operating costs for the latest auxiliary equipment could be a deterrent.

Examples of energy-efficiency improvements with the latest technological interventions

The Indian cement industry is a pioneer in adopting the latest technologies to improve productivity and energy efficiency.

- A plant in Madhya Pradesh has upgraded its conventional clinker cooler with the latest generation energy-efficient clinker cooler. This has resulted in reductions of 15-20 kcal/kg of clinker in specific heat consumption. The power consumption of the cooler section was also reduced by 0.59 kWh/t of clinker.

- A company in Chhattisgarh has commissioned a new clinkerization line of 10,000 tonnes per day (tpd) with a 6-stage preheater. The new clinkerization unit is a state-of-the-art plant that is highly automated and has a latest generation energy-efficient clinker cooler. The specific heat consumption of the kiln is 697 kcal/kg clinker and the specific energy consumption of the kiln section is 13.0 kWh/t clinker.

- A plant in Rajasthan has installed a medium voltage variable frequency drive (VFD) instead of a grid rotor resistance (GRR) for a kiln hybrid bag house fan, which has resulted in savings of around 160 kW. The investment incurred was INR 6 million, with a simple payback period of 10 months.

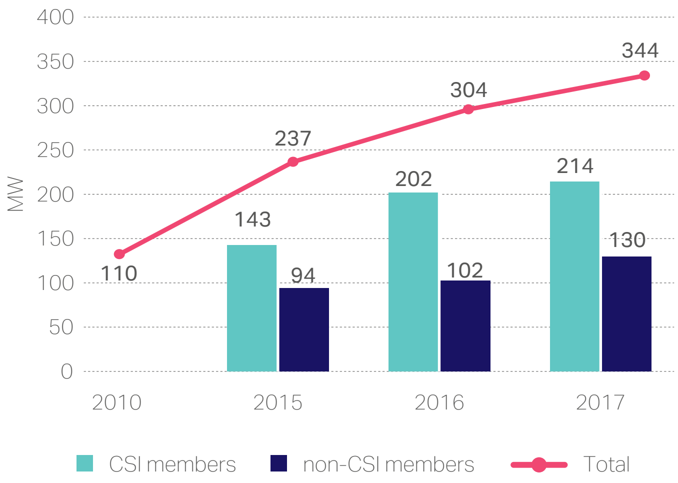
Lever 2: waste heat recovery system (WHRS)

Context

The adoption of WHRS in Indian cement plants offers several benefits, such as mitigating greenhouse gas emissions and achieving PAT cycle targets. This may ultimately contribute to long-term energy security in India. According to the latest Confederation of Indian Industry (CII) data, the total waste heat recovery potential in India is 800 MW, of which the major cement plants across the country are currently tapping 43%.

The country has seen a three-fold increase in WHRS installations, from 110 MW in 2010 to 344 MW in 2017 – an increase of more than 230 MW in installed capacity in seven years. Growing energy costs, including that of coal and grid electricity, have been the primary driver for cement manufacturers to opt for WHRS. Since its introduction in 2010, the Clean Energy Cess[4] on coal had increased 700% by 2017. At present, 25 cement plants have installed WHRS in some 47 kilns across the country. Given the surging input costs and rising emphasis on adopting environmentally friendly production techniques, the importance of WHRS for the cement sector is increasing. All such systems installed in Indian cement plants are self-financed and use a Rankine cycle, except one which uses an Organic Rankine cycle. CSI member companies had 62% of the total WHRS installed capacity in 2017.

Figure 13: WHRS installed capacity (MW)



Market changes and improvements observed

From 2010 to 2017, the major WHRS improvement has been the installation of recirculation systems to maximize power generation on the cooler side.
The PAT scheme has been a major driver in accelerating the adoption of WHRS in cement plants. The use of mechanisms such as internal carbon pricing has also helped companies make the business case for implementing WHRS.

WHRS catalyzes electrical energy savings

Waste heat recovery plants contribute significantly to electrical energy savings (to the tune of 25%). The total installed capacity of WHRS in the Indian cement industry has increased from 107 MW in 2011 to 344 MW in 2017. WHRS is installed in some 47 Kilns in 25 different locations in India.

A plant in Rajasthan has 103 MW of WHRS installed in a single location. All units at this plant have WHRS in both preheater and cooler sections. The total investment for the project was around INR 1.9 billion. This company was the first to register a WHRS project with the United Nations Framework Convention on Climate Change (UNFCCC).

[4] A cess is an additional tax imposed besides the existing tax (tax on tax) in India.

Challenges to implementation

WHRS are among the most cost-effective ways to increase the overall efficiency of a plant while reducing fuel demand. Data reveals that co-generation of power using waste heat meets 25-30% of total cement plant power requirements. It is estimated that the Indian cement industry has the potential to produce 800 MW through co-generation of power using WHR, of which only about 40% is being tapped. Further gains will not only reduce cement production costs; it will also help reduce GHG emissions.

The key barrier that most of the large cement manufacturers in India that opt for WHRS face is the capital expenditure required for installation and maintenance. Limited indigenous suppliers and service providers and lower cycle efficiency adds to the overall operational costs of WHRS.

Additionally, there are no policy drivers that incentivize the co-generation of power from waste heat. A policy initiative to consider WHRS under the Renewable Purchase Obligation (RPO) could significantly scale up capacities.

Lever 3: alternative fuels and raw materials

Context

The growing demand for fuel and raw material in the cement industry can be partly satisfied by using different alternative fuels and raw (AFR) materials.[5] Many cement plants across the country have already started using AFR and a few are in the process of setting up systems to use AFR. The Government of India has also come up with initiatives through Central and State Pollution Control Boards (CPCB & SPCBs) that aim to increase AFR use in the cement industry.

Details on fuels used in 2010 were not available during the year of preparation of the LCTR.

Over the years, petcoke consumption has increased steadily in the Indian cement industry. Coal use (Indian and imported) has been declining over the years and petcoke and alternative fuels are gradually replacing it. In 2017 the share of coal was 41% while that of petcoke was 56% and alternative fuels was 3%.

Changes in the fuel mix have lowered carbon intensity by 2 $kgCO_2/t$ cement. The overall emissions factor (for coal and petcoke) decreased to 94.1 $kgCO_2/GJ$ in 2017 from 94.7 $kgCO_2/GJ$ in 2010.

Figure 14: Share of various fuels (%)

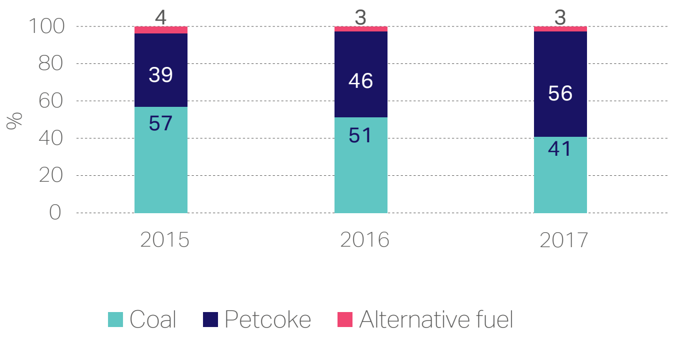
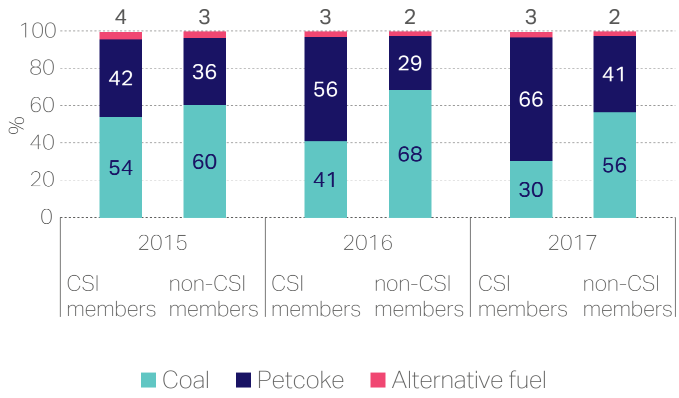


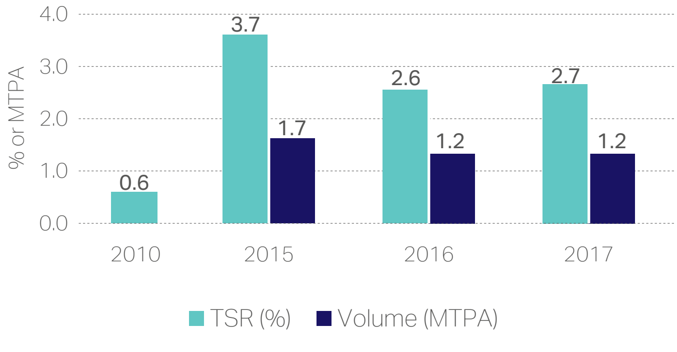
Figure 15: Share of various fuels - CSI & non-CSI companies (%)



Alternative fuel use (thermal substitution rate – TSR) increased from 0.6% in 2010 to 3.7% in 2015 and then dropped to 2.7% in 2017. The upward trend in alternative fuel use tapered off in 2016 and 2017 due to the comparative increase in prices of certain alternative fuels, making them uncompetitive to use instead of conventional fuels. This trend is expected to reverse and climb in the years to come due to improved economics. More than 60 cement plants in India have reported continual use of alternative fuels. The sector consumed more than 1.5 million tonnes of alternative fuels in 2015. Biomass is 24% of the total alternative fuel consumed.

The increased use of petcoke can be attributed to its higher calorific value (around 8,000 kcal/kg) as compared to Indian coal (3,500-4,500 kcal/kg) and the economic advantages derived from affordable pricing models. For the same amount of heat, the quantity of petcoke required is less than that of coal, which leads to savings in transport costs, considering the quantities of fuel transported. Petcoke use also increases the overall life-span of mines as the industry can use marginal grade (quality) limestone with a low lime saturation factor (LSF) (due to less ash content). In about 10 cement plants, petcoke consumption is more than 95%.

Figure 16: Alternative fuel consumption



[5] In this section, we limit the discussion on AFR to alternative fuels. We cover the use of alternative raw materials in the section on clinker substitution.

Market changes and improvements observed

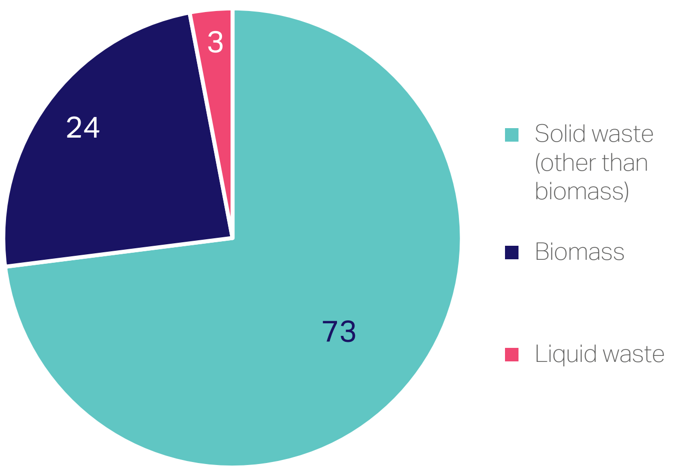
Many plants have started co-processing waste as alternative fuels by setting up co-processing facilities. Seven cement plants have set up pre-processing facilities to convert non-homogeneous wastes into alternative fuels with the desired quality parameters. The total investment by these seven plants is more than INR 2.5 billion.

Regulatory drivers have also accelerated the co-processing of waste by cement companies. The Ministry of Environment Forests and Climate Change (MoEFCC) issued its Solid Waste Management Rules in 2016. These rules give preferential status to the co-processing of waste as a management option. Some SPCBs have approved inter-state transportation of hazardous waste to encourage co-processing. Together, these have resulted in increasing alternative fuel use.

Indian cement plants have used different types of waste as alternative fuels. Solid waste is 73% of total alternative fuel use. The major types of solid waste used are carbon black, tire chips, refuse-derived fuel (RDF), captive power plant (CPP) bed ash and dolachar.

There is significant potential for higher rates of RDF use generated from municipal solid waste (MSW). About 80% of the estimated 62 million tonnes of MSW generated in India is indiscriminately disposed of in dump sites.[ix] In a business-as-usual (BAU) scenario, India will require a landfill area of 8,800 hectares by 2050. This is equivalent to the size of the city of New Delhi. By using 25% AFR by 2050 (as per the objectives of the LCTR), the cement industry can contribute to a 26% reduction in the space required for landfilling.

Figure 17: Alternative fuel types (%)



Policy driver: Solid Waste Management Rules 2016

The MoEFCC recently notified its new Solid Waste Management (SWM) Rules 2016. These replace the Municipal Solid Wastes (Management and Handling) Rules 2000.

One of the major highlights of the new rules is the promotion of waste-to-energy in cement plants using co-processing systems. The rules mandate that all industrial units using fuel and located within 100 kilometers of a solid waste-based RDF plant must make arrangements within six months from the date of notification of these rules to replace at least 5% of their fuel requirement by RDF.

The rules also direct that non-recyclable wastes having a calorific value of 1,500 kcal/kg or more need to be used to generate energy at waste-to-energy plants or giving it away as feed stock for the preparation of refuse-derived fuel for cement kilns. High-calorific wastes shall be used for co-processing in cement or thermal power plants.

Policy driver: Central Pollution Control Board (CPCB) guidelines on pre-processing and co-processing of hazardous and other waste in cement plants and the Hazardous Waste Management Rules 2016

The CPCB has released a comprehensive set of guidelines on "Pre-processing and co-processing of hazardous and other wastes in cement plants" as per the Hazardous and Other Waste (Management and Transboundary Movement) Rules 2016, via a notification dated 7 July 2017. The proposed guidelines are in line with the recently notified Hazardous Waste Management Rules (HWM) 2016 wherein companies must consider prevention, reuse, recycling, recovery and use, including pre-processing and co-processing, prior to considering disposal through incineration or secured landfilling. The objective behind this measure is to ensure millions of tonnes of hazardous, municipal and agricultural waste is either properly recycled or disposed sensibly in order to reduce India's overall environmental footprint. It is preferable to use cement kilns to dispose of hazardous wastes due to longer retention times, high temperatures and the absence of residual ash or byproducts.

Although various industrial processes allow for the use of wastes as a resource or for energy recovery, co-processing in cement kilns is considered an effective and sustainable option because of its dual benefits – as a supplementary fuel source and as an alternative raw material. Furthermore, the biomass content of alternative fuels is considered carbon neutral.

As per the proposed guidelines, such use would help in recovering the energy and material values present in them by reducing the consumption of primary fossil fuels and raw materials.

The following attributes of the recently released guidelines have been a major driver for Indian cement companies to increase the use of AFR in their plants:

- Authorization for pre-processing and/or co-processing: Under the proposed guidelines, SPCBs)/Pollution Control Committees (PCCs) may grant authorization to cement plants to co-process different kind of wastes listed in the Hazardous and Other Wastes (Management and Transboundary Movement) Rules 2016.

- Trial runs: Fresh trial runs for the co-processing of hazardous wastes already tested and in the system, would not be necessary as per the proposed guidelines, except for a few specific wastes, such as persistent organic pollutants (PoPs), polychlorinated biphenyls (PCBs), obsolete and date-expired pesticides, ozone depleting substances (ODS), etc.

HWM Rules 2016, streamline the approval process for the co-processing of hazardous waste to recover energy and put it on an emission norms basis rather than on a trial basis.

Policy driver: Guidelines on usage of refuse-derived fuel in various industries, Ministry of Housing and Urban Affairs (MoHUA) 2018

The Guidelines adopt a waste management hierarchy and resource recovery principles and include recommendations on the use of RDF in cement plants. They also include suitable standards for RDF along with guidance for different stakeholders.

The estimated quantity of MSW-based RDF and mapped cement plants within 100 and 200 kilometers of urban areas highlight the use potential of RDF in cement plants. The Guidelines map MSW processing facilities across the country to facilitate faster implementation between Urban Local Bodies (ULBs) and the cement industry. To create a viable business model, they define the financial needs, gaps and instruments for fiscal incentives.

These Guidelines should enhance the use of MSW-based RDF in the cement industry in the future.

Alternative fuel feeding platform and processing

Many cement plants are installing co-processing and pre-processing platforms to increase alternative fuel use. One plant in Madhya Pradesh has installed a pre-processing platform consisting of a shredder, belt conveyors, pay loaders, separators and screens, and increased TSR from 0.64% to 8.8%. The total investment was around INR 620 million. The plant uses various wastes, such as agricultural waste (rice husks, soya husks), saw dust, plastic waste, RDF, effluent treatment plant (ETP) sludge, spent carbon, carbon black, etc. Plants in the states of Karnataka, Chhattisgarh, Rajasthan, Gujarat, Maharashtra and Tamil Nadu have also installed co-processing and pre-processing platforms.

Challenges to implementation

Although cement kilns could technically completely replace conventional fuels with alternative fuels, there are some practical limitations. The physical and chemical properties of most alternative fuels differ significantly from those of conventional fuels. It may not be directly used because of low calorific value, high moisture content, or high concentrations of chlorine or other trace substances. This means pre-treatment is often needed to ensure a more uniform composition and optimum combustion. For Indian cement plants to increase TSR by 25% (in 2050), a major barrier is cost of material sourcing and acquisition. The cost of sourcing the material should be regulated by applying polluter pays principle. Higher fuel substitution will take place if waste legislation restricts landfilling and dedicated incineration and allows controlled collection and treatment of alternative fuels.

The main technical barrier is the adverse impact created on kiln production and specific energy consumption. The companies are in the process of developing a complete understanding of the impacts of minor constituents and what effects they might have on long-term cement performance.

The government must provide incentives for the use of RDF derived from municipal solid waste and biomass to promote high-volume use of these AFRs to meet the 25% TSR target by 2050.

One of the key policy barriers that existed at the time of the launch of the LCTR in 2013 was the absence of a legislative framework that encourages co-processing in the cement industry. With the SWM Rules 2016 and their clear objective to promote co-processing and pre-processing of waste, this barrier has ceased to exist. However, other major policy barriers for increased use of AFR include the non-existence of structured industrial ecosystems for waste co-processing and inconsistent legislative requirements for cement kilns and their dedicated waste processing facilities.

The industry requires a future-forward approach to promote waste co-processing. Some of the desired interventions include:

- The implementation of proper segregation and collection of dry and wet waste from households and commercial and industrial establishments.
- User fees for waste generators (including households) and their use for managing MSW and cement-grade RDF generation.
- Government support of ULBs in implementing integrated waste management systems.
- Government permission to freely move wastes from state to state.
- Government efforts to create awareness and promote high levels of waste use through waste management awards and recognition through avenues including print media, school programs, etc.
- Detailed waste generation inventory at the industry/ULB level (including contact persons) with yearly updates.
- Capacity building for all stakeholders (cement plants, policy-makers, waste generators, government officials, local communities, etc.) about waste co-processing.
- The development of environmental professionals in waste management.
- Long-term partnerships between cement manufacturers and ULBs to use RDF from MSW, including pre-processing platforms in public-private partnership (PPP) models in all cement clusters.

Lever 4: clinker factor reduction

Context

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 byproduct 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 the fuel and power-related CO_2 emissions associated with clinker production.

The share of blended cement production in total quantities of cement manufactured in India was 68% in 2010, which remained almost same in 2015. However, in 2016 and 2017 blended cement production increased to 73% of total cement production. Increased acceptability by the market, growing awareness of sustainability concepts, the availability of fly ash from thermal power plants and the use of advanced technology triggered this rise. PPC production in 2010 was 61%; this increased to 65% in 2017. The share of PSC production has been almost flat, at less than 10%, although the absolute volume grew by about 40% in the last seven years.

Figure 18: Product mix (%) - overall

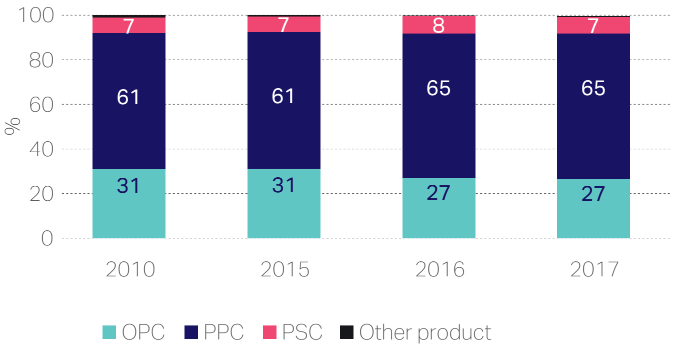


Figure 19: Product mix % (CSI members)

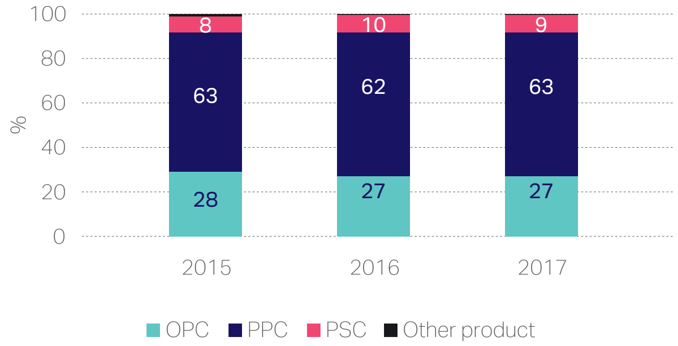
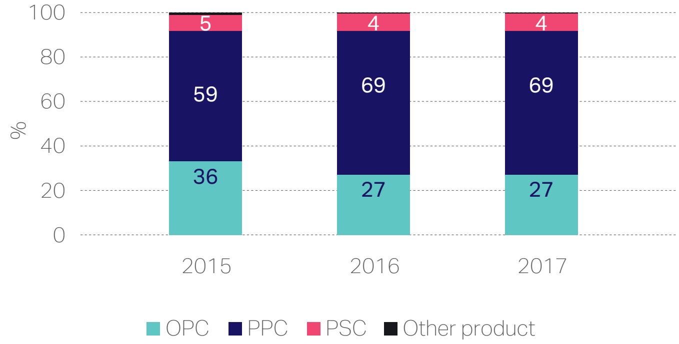


Figure 20: Product mix % (non-CSI members)



The Indian cement industry has been gradually increasing the share of blended cements in its cement mix. We have identified an overall improvement in the clinker factor, which was 0.74 in 2010 and gradually decreased to 0.71 by 2017, when about 280 Mt of cement was produced. This has a strong impact on energy consumption and CO_2 emissions reductions. The PPC clinker factor improved to 0.65 in 2017, compared to 0.68 in 2010. Fly ash consumption in 2017 was 31%, compared to 27% in 2010. The PSC clinker factor improved to 0.40 in 2017, compared to 0.55 in 2010, with an increase in PSC slag consumption to 57% in 2017 from 40% in 2010. Improvements in clinker quality and the higher use of petcoke as fuel are behind this change. In 2017, fly ash and slag consumption in cement was around 57 Mt and 12 Mt respectively.

Table 2: Clinker factor of different cement types

Type of cement	Clinker-to-cement ratio			
	2010	2015	2016	2017
OPC	0.95	0.94	0.94	0.94
PPC	0.68	0.66	0.66	0.65
PSC	0.55	0.45	0.43	0.40
Overall	**0.74**	**0.73**	**0.72**	**0.71**

Figure 21: Clinker factor of CSI members

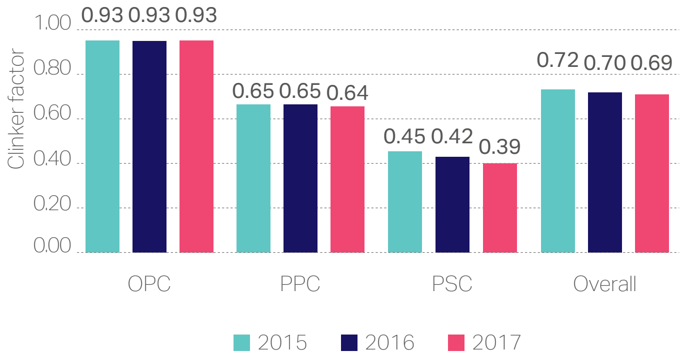


Figure 22: Clinker factor of non-CSI members

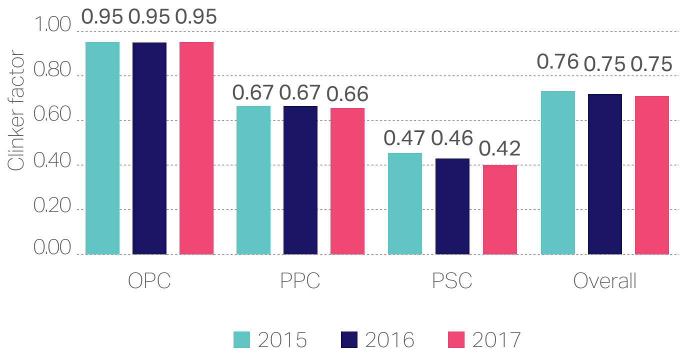


Figure 23: Mineral component (MIC) consumption in cement – overall

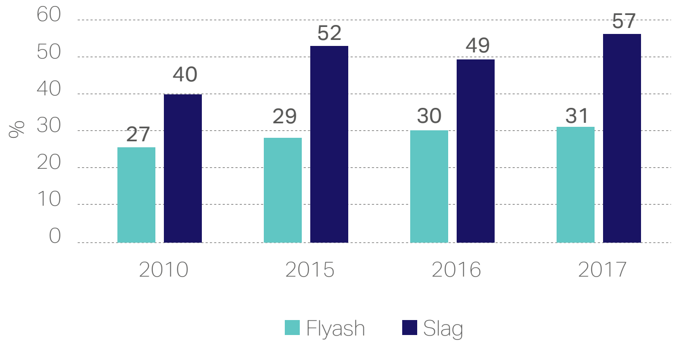


Figure 24: Mineral component (MIC) consumption in cement - CSI members

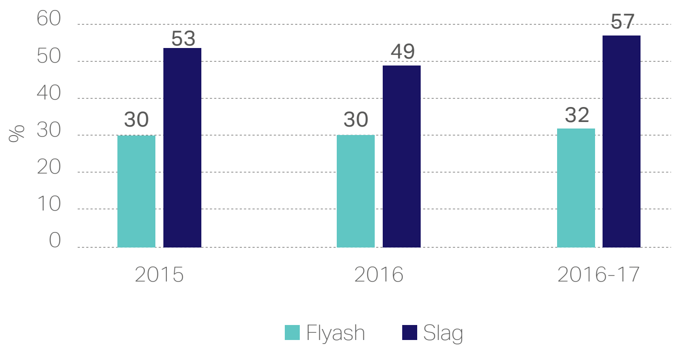
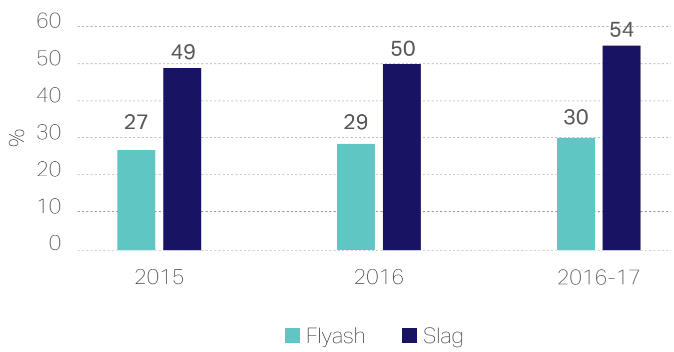


Figure 25: Mineral component consumption (MIC) in cement - non-CSI members



Market changes and improvements observed

From 2010 to 2017, we have observed the following major improvements with respect to clinker substitution:

- Increased fly ash addition in PPC.
- Increased slag addition in PSC.
- Improved clinker quality due to use of petcoke.
- Diversification of product mix with introduction of composite cement.

Increase in fly ash addition from 26% to 34% in PPC manufacturing

Improvements in the clinker factor by increasing the fly ash addition in PPC has shown a steady rise – from 26% in 2011 to 34% in 2017 – in a cement plant in Karnataka. The cement plant implemented the following measures: the construction of a new fly ash silo with a capacity of 5,000 tonnes to increase total fly ash storage capacity to 12,500 tonnes; continuous trials in the laboratory; optimization of the raw mix; and the installation of a roto scale to accurately feed fly ash. The fly ash and bed ash generated in the captive power plant was also fully used.

Many other cement plants have also taken measures to increase the fly ash proportion in PPC manufacturing.

Policy driver: issuance of standards for composite cement

Gradually depleting limestone reserves indicate that clinker production requires an appropriate substitute. To address this issue, one of the most common measures that cement plants in India have been adopted is the production of composite cement.

In December 2015, the Bureau of Indian Standards (BIS) released standards (IS 16415:2015) for the production of composite cement. This cement is produced by adding fly ash and slag together in Portland cement. The standard covers requirements such as its manufacture, chemical and physical requirements, packing and marking. It covers material requirements such as fly ash and granulated slag and their proportions that are to be used in the manufacturing of composite cement.

Cement plants can produce composite cement either by thoroughly inter-grinding Portland cement clinker, granulated slag and fly ash or thoroughly and uniformly blending OPC, finely ground granulated slag and fine fly ash with the required addition of gypsum.

Table 3: Material proportion for the production of composite cement

Material	Proportion (percentage by weight)
Portland cement clinker/OPC	35 - 65
Fly ash	15 – 35
Granulated slag	20 – 50

Source: Bureau of Indian Standards

Composite cement production with low clinker factor

Composite cement has a considerably lower production cost as well as a lower CO_2 intensity. Composite cement production in a one MTPA cement plant requires 57% less raw material, 52% less thermal energy and 34% less electrical energy in comparison to OPC production.
The CO_2 emissions intensity of composite cement is 0.36 tCO_2/t of cement, which is 56% lower than OPC.

Many Indian cement plants have started manufacturing composite cement.

The manufacture and use of composite cement is desirable for maximizing the use of waste materials and for better control over cement properties. Composite cement production offers various benefits over OPC and other blended cements, including reductions in limestone consumption, thermal energy and electrical energy consumption and CO_2 emissions intensity.

Challenges to implementation

Being the key ingredient in cement, the amount of clinker used is directly proportional to the CO_2 emissions generated in cement manufacturing due to both the combustion of fuels and the decomposition of limestone in the process. While global cement production will continue to grow at an average annual rate of 0.2% until 2030, it is important that the clinker-to-cement ratio decline to the global average of 0.64 by 2030. This can be done through increased use of blended cements and clinker substitutes, including industrial byproducts such as blast furnace slag or fly ash. In the long run, alternative clinker replacements that are widely available, such as calcined clay in combination with limestone, will play a vital role, as the decarbonization of power generation and iron- and steelmaking reduces the availability of these industrial byproducts.

For new types of cement, durability, early strength development, workability, cost and low environmental impacts are essential requirements. Depending on its composition, cement can fulfill these criteria to different degrees. It is the remit of the producer to optimize the different cement types with respect to these categories. Compliance with norms on carbonation resistance, resistance against chloride penetration, etc. are also mandatory.

In India, cement manufacturers are currently facing critical barriers in increasing the substitution of clinker. Some major ones include regional non-availability of fly ash and slag and the cost matrix. Varying consumer acceptance across the construction sector is also a concern.

The availability of slag limits the production of PSC and composite cement. The cement industry is currently using nearly all the granulated slag.

The use of OPC should be restricted to special applications and the rate of taxation should be proportional to the CO_2 footprint of the cement to encourage blended cements.

Fast adoption of limestone-based and calcined clay-based cements, including Limestone Calcined Clay (LC3) cement is needed, along with recognized standards for these blended cements. This will help reduce the clinker factor further.

Limestone calcined clay (LC3) cement [6]

LC3 is a ternary cement that can achieve strengths similar to OPC, even at clinker factors as low as 40% to 50%. LC3 is the result of an international collaboration between the University of Las Villas, Cuba and the Ecole Polytechnique Fédérale de Lausanne, Switzerland, using funding from the Swiss Government. With funding from the Swiss Development & Cooperation Agency (SDC), researchers from IIT Delhi, IIT Madras and IIT Bombay are working with the personnel of TARA to understand and develop LC3 for the Indian cement Industry.

Advantages of LC3:

- Reduction of clinker content in cement by 50%.
- Low calcination temperature of clay.
- Can be used with existing manufacturing equipment.
- Lower cost of production.
- Use of low-grade clay and low-grade limestone.

Organizations have carried out two LC3 pilot productions, producing around 170 tonnes of five different blends of the cement. A laboratory has produced and tested several other LC3 blends. Organizations have carried out wide-ranging laboratory and field studies on LC3 in India. Research is underway to determine the quantities of clay available in cement clusters in the country. The results are promising but commercialization of this technology is subject to approval by BIS.

[6] For more details, refer to https://www.lc3.ch/ and http://web.iitd.ac.in/~bishnoi/lcc/LCCProjectSummary.pdf

Lever 5: newer technologies

While the LCTR does not specify any targets for this lever, the recently updated global technology roadmap: Low-carbon Transition in the Cement Industry (2018)[x] estimates that emerging and innovative technologies will provide 3.7 Gt CO_2 or 48% of the cumulative CO_2 emissions savings by 2050 globally in the 2-degree Celsius Scenario (2DS[7]) compared to the Reference Technology Scenario (RTS).[8] This is equivalent to 166% of current direct CO_2 emissions of global cement production.

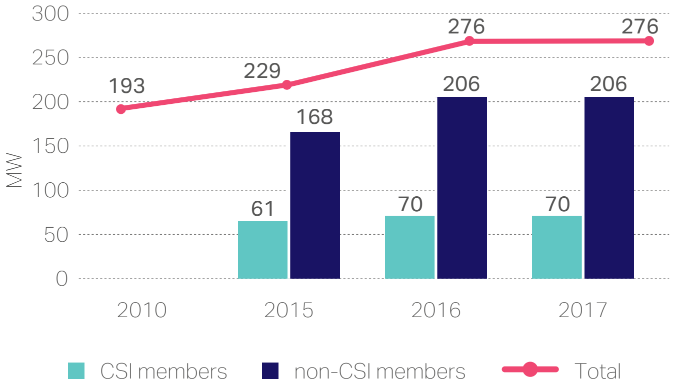
Organizations have not reported any significant breakthroughs other than notification of composite cement standards and pilot scale demonstrations of LC3 in the period under review.

Renewable power generation

Most of the plants in the Indian cement industry are already equipped with the latest available electrical system technology, such as intelligent motor control centers (MCC) and energy management systems (EMS), the latest energy-efficient kilns and the latest generation coolers with high recuperation efficiency.

However, the cement sector can support further carbon emissions reductions from electricity production by increasing the share of renewable power in its overall power consumption. The renewable energy installed capacity (wind and solar) in cement plants increased by more than 40% to 276 MW in 2017. Of the current stock, 42 MW is solar power, while off-site wind installations account for 234 MW.

Figure 26: **Renewable energy installed capacity (MW)**



Most cement plants in India are in dry and hot areas with enormous solar radiation and have huge amounts of unused, unshaded arid land. This setting provides optimum conditions for the deployment of solar power generation plants. Several cement manufacturers have ventured into solar power generation in India.
A company has undertaken the target of switching over to renewable energy for 100% of all electrical energy needs by 2030.

A significant increase in renewable energy capacity addition has some challenges in the Indian scenario. In terms of renewable resources, sites with high wind energy potential are geographically limited and most such sites have already been used.

Wind and solar are both intermittent sources of power and require another power generation source to meet the baseload requirement.

Having said that, the share of renewable power, especially using wind and solar energy, can be increased in a company's power consumption mix. In many cases, this can be done in a cost- effective manner.

However, any meaningful increase in the cement sector's share of renewable power in India requires policy support and regulatory certainty. Regulatory processes and applicable charges for transmission, wheeling and banking of power are still unpredictable across most parts of India. This is a major impediment to increasing renewable energy procurement by most large power customers, including the cement sector. While some states have announced progressive policies in this regard, these are not widespread across the country. The cement sector is keen to see some of these policy and regulatory issues resolved soon. This will allow the sector to increase the share of renewable power consumption that can lead to a further reduction in its carbon emissions.

[7] Please refer to Annex A for definitions of scenarios.

[8] Please refer to Annex A for definitions of scenarios.

Carbon capture, storage and use (CCS&U)

Some cement plants in India have undertaken pilot projects for carbon capture through algal growth and use as biofuels. The major barriers to the mass adoption of this technology are lack of economies of scale and water availability. Researchers are exploring ways to overcome these barriers.

One cement plant co-located with a paper manufacturing unit is successfully using CO_2 from the cement and lime kilns to produce calcium carbonate. This is used in the paper and pulp unit as a filler. This indicates that companies could develop many customized CCU solutions to suit local requirements. Collaborative research between the cement and paper sectors could help in scaling such circular solutions.

Further research and development are required to make new technologies like CCS and CCU affordable as the cost will eventually be borne by the consumer. Moreover, the Government of India is yet to announce a clear policy direction on adoption and uptake of CCS in the country.

Oxygen enrichment

Improving the combustion process and increasing heat recovery has always been the aim in fuel use processes. Optimizing excess air, increasing flame momentum, preheating combustion air and improving burnability/mixing of coal and air are various techniques tested to improve combustion. Oxygen enrichment is another tool that can significantly improve combustion efficiency. With the introduction of oxygen-enriched combustion, energy requirements in the kiln could decrease between 84 and 167 MJ/t cement. Though practiced widely in other industrial sectors, such as metal processing (steel, copper, etc.) and furnace treatment, it has yet to gain popularity in the cement sector.

Adopting oxygen enrichment can lead to significant improvements in the burning zone temperature and resultant heat transfer to material. It can also provide an opportunity to burn difficult fuels (e.g., fuels with poor combustion characteristics) and reduce combustion gas/preheater exit gas volumes.

Reductions in combustion gas volume due to increased oxygen levels can redefine the specific power consumption of preheater fans and reduce specific heat consumption by improving heat transfer in preheater systems leading to lower preheater tower exit temperatures and the elimination of carbon monoxide formation. It is estimated that a 2% increase in the oxygen level in the burning zone (kiln combustion) can lead to an 8% reduction in preheater gas volumes, resulting in an SEC reduction of 0.5 kW/t clinker or an equivalent increase in production or significant use of alternative fuels. However, the effect of NOx formation in oxygen enrichment is yet to be studied relative to recent emission norm mandates.

A few case studies from the United States prove the benefits of oxygen enrichment. However, the higher initial investments needed (including the safety measures to be adopted) leading to longer pay back periods (close to five years) and higher operating cost to produce, store and use oxygen unless compensated by negative cost from the use of alternative fuels are preventing the Indian cement industry from widely adopting this technology.

Other emerging options[xi]

- All input materials (e.g., limestone, coal, petcoke and additives) have an average moisture content of 5% to 10%. Technology harnessing solar power, such as solar concentrators and heaters to dry input materials and preheating meal feed, need to be explored.

- Bamboo has now been brought under the grass category. It could be interesting to explore the use of bamboo as an alternative fuel by planting on mining land or as part of social forestry programs or community farming.

Challenges to implementation

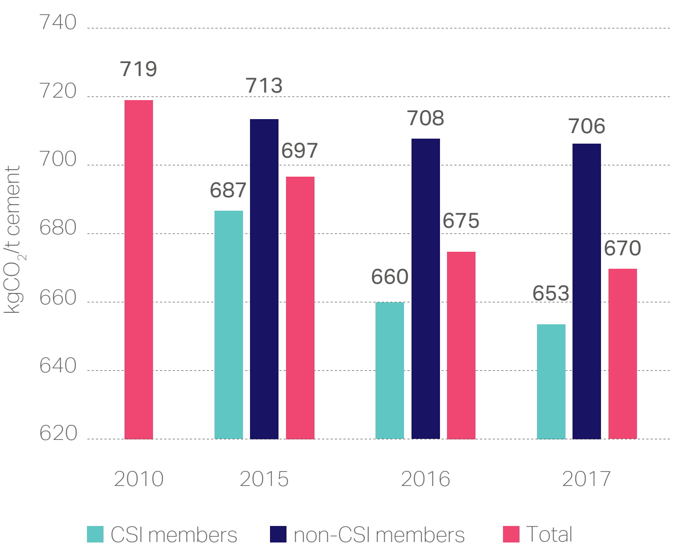
Investments in R&D and unproven economies of scale are the key barriers for some of the emerging and innovative technologies. CCU needs cooperation across industries for use of the final product.

Reduction potential from captive power generation

Captive power plants (CPPs)[9] are an integral part of cement manufacturing plants in India as they meet 60% of their electrical power requirements. Efficiency improvements and the use of renewable energy in CPPs is essential to supporting the Indian cement industry's endeavor to move towards a low-carbon economy.

The CO_2 emission intensity (including onsite/CPP power generation) decreased by 49 $kgCO_2$/t cement to 670 kg CO_2/t cement in 2017 compared to the baseline year.

Figure 27: CO_2 emissions intensity, including CPP/onsite power generation ($kgCO_2$/t cement)



Market changes and improvements observed

Over the last seven years, energy-efficiency improvements through CPPs have observed the following sectoral dynamics:

- Smaller CPPs have been slowly moving towards circulating fluidized bed combustion (CFBC) boilers, which have higher combustion efficiencies than atmospheric fluidized bed combustion (AFBC) and travelling grate boilers.
- Most cement plants are now using higher efficiency fans and pumps.
- To improve overall auxiliary power consumption (APC), plants are extensively using VFDs in fans, pumps and compressors.
- Plants are using online condenser tube cleaning for improved vacuum.
- Plants are using energy management systems, online performance management, oxygen trim controllers and other advanced automation system for overall performance improvement as well as improved monitoring.
- Plants are using three-phase transformers and high-frequency transformers in existing electrostatic precipitators (ESPs) to improve overall dust collection efficiency.
- Plants are using pinch analysis software to improve CPP efficiency.

Policy drivers

The introduction of emissions standards for NOx emissions and specific water consumption have contributed substantially to driving the overall emission intensity footprint of CPPs. Increased combustion efficiency for NOx reduction contributes to reducing energy consumed. The new norms require reductions in specific water consumption. This implies reductions in energy used for water treatment and pumping.

Challenges for implementation

CPPs in cement manufacturing units are facing challenges in implementing the latest energy-efficient technologies and issues of inconsistent coal quality, layout constraints on technical aspects, performance of air-cooled condensers and grid connectivity for increased CPP plant load factors. The cost of retrofitting is high; the installation of storage and blending systems for multi-fuel use requires high capital expenditures and has a longer payback period.

[9] Fuel used in CPPs is partly lignite and mostly coal.

Investment needs and mobilizing financial support

The industry requires significant investments in the transition to a low-carbon future. LCTR 2013 maps the cumulative investment needs in the Indian cement industry from 2010 – 2050. Landmark events such as the negotiation of the Paris Agreement in 2015 and its subsequent ratification by 184 parties, including India, and the adoption of the Sustainable Development Goals have taken place since 2013. The CSI at the global level also released in partnership with IEA an updated Technology Roadmap: Low-Carbon Transition in the Cement Industry in early 2018. Considering these developments, the Status Review also analyzed the cumulative investment needs from 2020 to 2050 using the updated IEA methodology. We used data for 2015 as a baseline for this investment analysis.

The Indian cement sector needs between USD $12 billion[10] and USD $25 billion net cumulative additional investment costs to implement the 2-degree Celsius Scenario (2DS) compared to the 6-degree Celsius Scenario (6DS).[11]

The integration of carbon capture technologies in cement production in 2DS accounts for between USD $41 billion and USD $52 billion in cumulative additional investment needs by 2050 in India. This represents the largest investment requirement compared to 6DS. Investment costs associated with carbon capture exclude CO_2 transport and storage costs. These investment estimates are sensitive to the future evolution of carbon capture technology costs as they are demonstrated at greater scales. Reported CO_2 abatement costs in techno-economic studies performed for theoretical cement plants range from about 55-70 USD/tCO_2 avoided for oxy-fuel technologies and about 90-150 USD/tCO_2 avoided for post-combustion, subject to reference plant size and excluding CO_2 transport and storage.[xii]

Reducing the clinker-to-cement ratio in the 2DS is estimated to incur more modest additional cumulative investments, between USD $6.5 billion and USD $8.6 billion, whereas those associated with shifting to using fuels that are less carbon intensive are estimated at between USD $1.1 billion and USD $3.4 billion by 2050 in India.

In 2DS, additional investments related to a wide uptake of state-of-the-art kilns and grinding technologies compared to less advanced equipment, as well as the addition of onsite power generation capacity based on WHR, are offset by the lower clinker production and raw material and fuel grinding demand resulting from ambitious energy-efficiency improvements and clinker-to-cement ratio reductions. Between USD $37 billion and USD $39 billion net cumulative savings globally are related to the shifts on kilns, grinding and WHR equipment used in the 2DS compared to the 6DS.

While increasing cement demand creates greater pressure on reducing carbon emissions to achieve 2DS, the installation of new cement capacity creates opportunities to integrate state-of-the-art technology in an advantageous situation compared to revamping projects.

[10] Investments are estimated based on 2015 USD$.

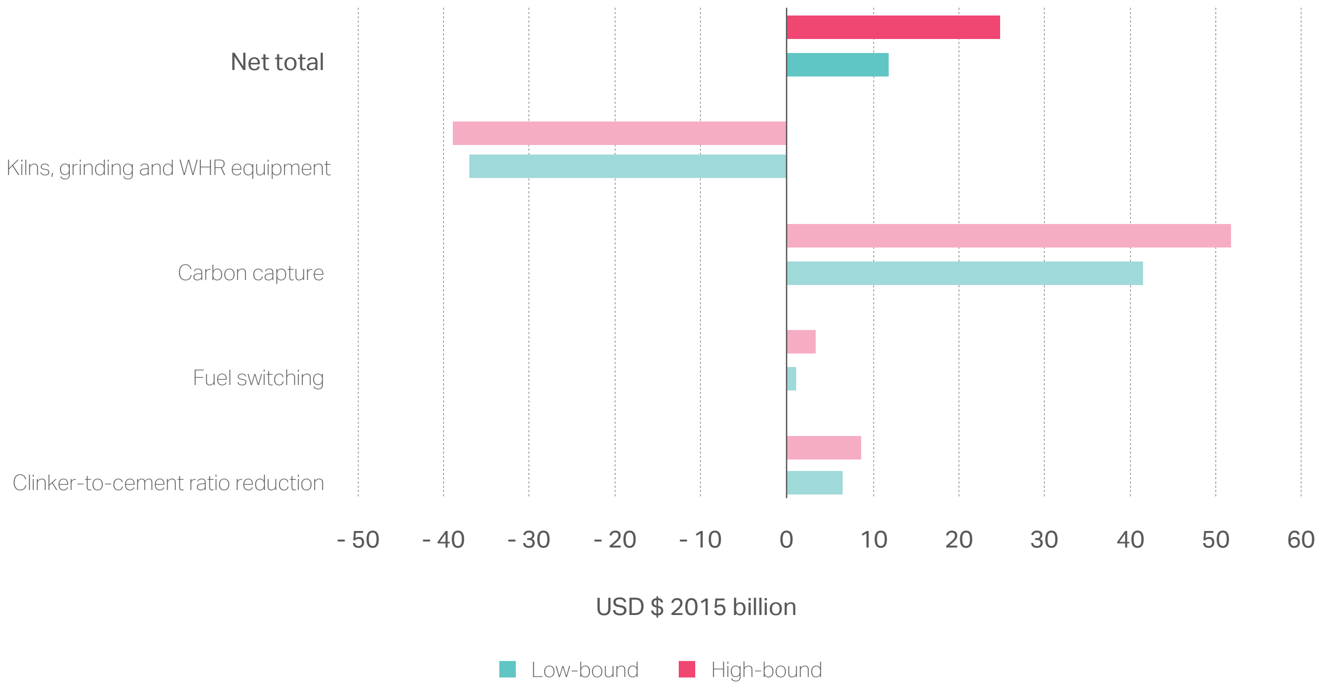
[11] Please refer to Annex A for details on scenarios.

Table 4: **Cumulative investment needs in the Indian cement industry, 2020-2050**

USD $ billion (2015)	6DS		2DS		2020-2050 Additional investments (2DS vs 6DS)	
	Low-bound	High-bound	Low-bound	High-bound	Low-bound	High-bound
Kilns, grinding and WHR equipment	94	99	57	60	-37	-39
Clinker-to-cement ratio reduction	0	0	6.5	8.6	6.5	8.6
Fuel switching	0	0	1.1	3.4	1.1	3.4
Carbon capture	0	0	41	52	41	52
Total	**94**	**99**	**106**	**124**	**12**	**25**

Source: IEA analysis

Figure 28: **Cumulative additional investment needs between 2DS and 6DS by 2050**



Source: IEA analysis

The impact of energy efficiency and reductions in the clinker-to-cement ratio on reducing activity partially offsets the global cumulative additional investments[12] in the roadmap vision (2DS), which are estimated at USD $12 billion to USD $25 billion compared to the 6DS.

Mobilizing financial support

There is an urgent need to mobilize public-private investment to support the sustainable transition of the cement industry. Robust carbon pricing can be one of the elements in the low-carbon transition of society, but governments worldwide struggle with implementation or with ensuring a stable price level. Traditional financing criteria used by industry are not appropriate for carbon mitigation technologies unless a carbon price or other incentive is high enough to adequately value the cost of reducing CO_2 emissions.

Governments should collaboratively pursue investment risk-mitigating mechanisms that are results-oriented and unlock private finance in areas with low likelihood of independent private investment. International collaboration is key in the development of such mechanisms to facilitate technology transfer, especially to expanding markets, as is the case of India, ensuring this way the deployment of innovative low-carbon technologies after successful demonstration.

In the past, CCS demonstration project funding has had a primary focus on power generation projects; but those should be expanded to explicitly target industrial applications, including in the cement sector. These mechanisms could reduce the risk associated with initial capital investments. They could also help investors to maintain a better cash flow by unlocking shares of total allocated financial support upon completion of predefined milestones through the development of demonstration processes. Funding of CCU projects also requires special attention.

Concessional climate finance is critical to supporting developing countries in building resilience to worsening climate impacts and to catalyzing private sector climate investment. The World Bank Group – along with other multilateral development banks (MDBs) – continues to make a strong contribution to the global climate challenge. IFC, the main member of), the World Bank Group, plays a key role in advancing climate solutions led by the private sector. IFC has pledged to step up climate investments to a goal of 28% of annual commitments for its own account, while moving to mobilize an additional USD $13 billion of financing from the private sector by 2020. In the cement sector, IFC has an investment exposure of around USD $4 billion globally in 32 projects in 26 countries. In India, IFC has invested and mobilized around USD $450 million in eight projects.

International foundations can also play an important role in supporting technology implementation and demonstration projects that contribute to the sustainable transition of cement manufacturing. The Mission Innovation initiative announced in 2015 is a global initiative of 23 countries, including India and the European Union, to dramatically accelerate global clean energy innovation. As part of the initiative, participating countries have committed to seeking to double their governments' clean R&D investments over five years, while encouraging greater levels of private sector investment in transformative clean energy technologies. These additional resources will dramatically accelerate the availability of the advanced technologies that will define a future global energy mix that is clean, affordable and reliable. The initiative has focused on seven innovation challenges, which include carbon capture and clean energy materials.[xiii]

Assessing investments

The investment estimates discussed in this section are based on bottom-up technology modelling of the cement sector, including full plant capital costs for industrial process equipment installed during the 2020 to 2050 period.

These are based on examining the low- and high-cost sensitivity boundaries of technology-specific investment costs to cope with the inherent uncertainty of assessing technologies that have not yet reached commercial readiness. The investment discussion is centered on the low-variability case analyzed as the reference case of this analysis.

Investment needs estimates do not consider any costs related to capacity already existing or incurred installation costs over the time horizon. Thus, no additional costs are allocated to energy savings from improved operation and maintenance practices. Also, the discussed investment costs do not capture site-specific potentials to reduce energy consumption or CO_2 emissions without a process change or major integration revamp due to their dependency on local conditions.

[12] Cumulative additional investment numbers are assessed considering low- and high-bound sensitivity ranges for specific investment costs.

The cost impact of activities outside the plant fence is not included. There may be costs related to alternative fuel collection or handling, or transport and storage of CO_2. Capital investments into carbon capture equipment do not include costs related to auxiliary equipment such as air separation units or organic Rankine cycles, which may be required when implementing new units/processes. Additional commodities needed to operate some of the innovative technologies, such as oxygen, are considered in the least-cost optimization as increased variable operating costs from importing such commodities. Costs associated with carbon capture include capital costs related to adapting kilns to oxy-fuel conditions.

Costs associated with switching to fuels that are less carbon intensive and reducing the clinker-to-cement ratio are related to the additional storage capacity onsite required to handle additional solid fuels and cement constituents, as well as to major new process equipment required (e.g., clay calciner capacity).

Coverage only includes major energy-consuming equipment, as enough data do not exist to accurately project the quantity and price of a wide range of small energy-consuming devices. As a result of this, given the more widely available information on the marginal cost of energy efficiency, 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.

Lastly, these estimates do not include investment costs related to R&D and pilot testing of novel technologies that are commercially deployed after 2030.

Table 5: Potential areas of investment for each of the technology levers

Technology lever	Technical aspects	Investment requirements
Electrical & thermal specific energy consumption (SEC) & efficiency improvements	For preheaters & kilns	• CFD study for pressure drop reduction: INR 1 - 3 million • Increasing efficiency of top cyclone: INR 1 - 5 million • Increasing calciner height for improvement in production: INR 10 -15 million • Low thermal conductivity bricks in kiln: INR 2 - 4 million • WHR from kiln shell radiation: INR 20 - 30 million
	For latest generation clinker coolers	• High-efficiency clinker cooler: INR 300 - 500 million • Reducing suction & silencer loss in cooler fans: INR 0.05 - 0.5 million
	For grinding systems	• High-efficiency separator for cement mills: INR 15 - 20 million • Installation of pre-grinder: INR 150 - 200 million • Latest generation vortex rectifier for VRM classifier: INR 20 - 30 million • Mill scan: INR 1 - 2 million • Separator optimization/modification: INR 5 - 15 million
	For retrofit uniflow burners	• Latest generation high efficiency burner: INR 20 - 30 million
	For process fans	• High-efficiency cooler vent fan: INR 5 - 10 million • High-efficiency PH fan: INR 7.5 -15 million • Reduction in pressure drop in duct: INR 1 - 2 million

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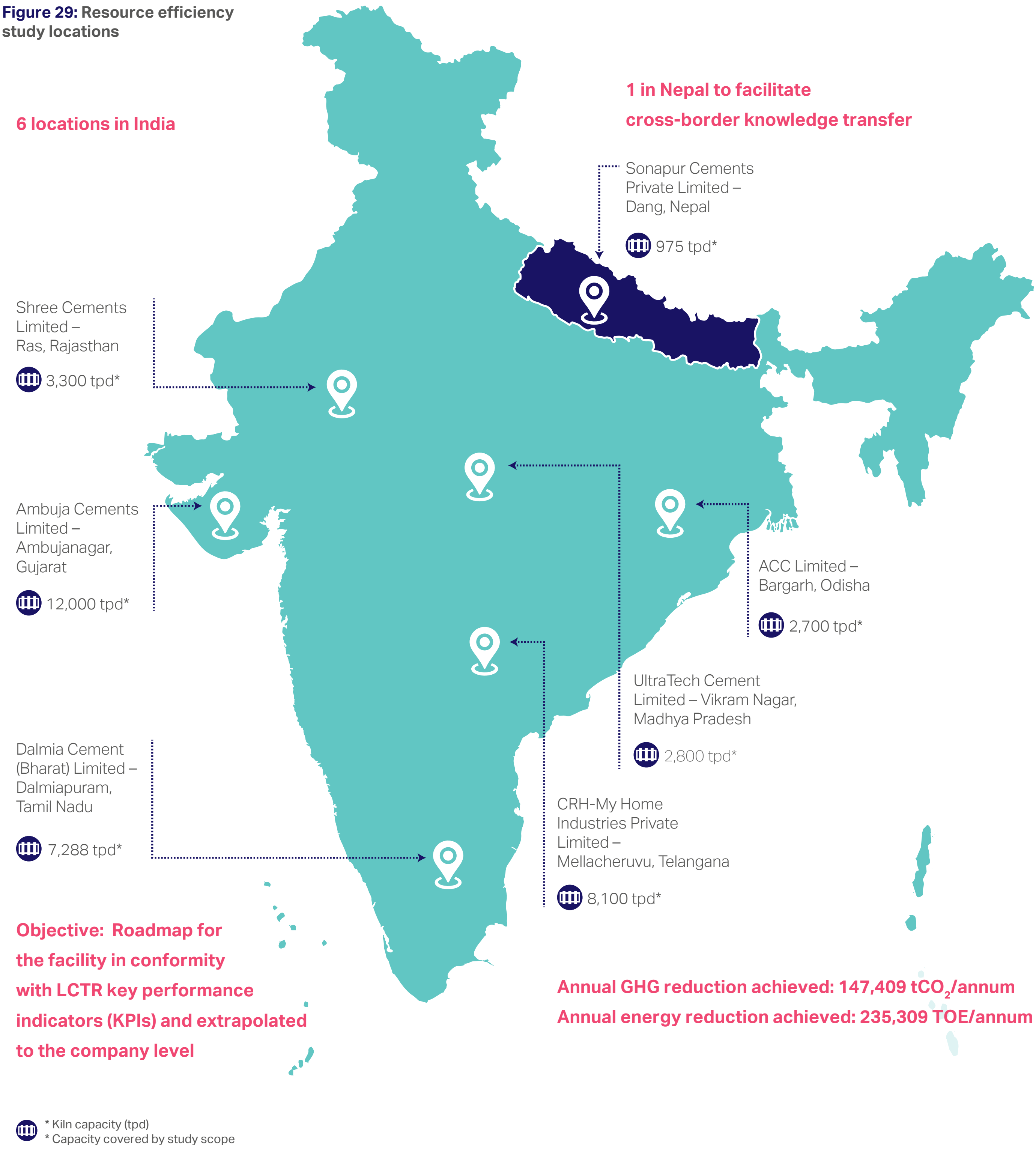
Technology lever	Technical aspects	Investment requirements
	For auxiliary equipment	• Energy-efficient blower: INR 5 - 10 million • VFD for compressor: INR 2 - 4 million • Energy-efficient compressor: INR 5 - 10 million • Low-pressure compressor: INR 3 - 5 million • Energy-efficient water pumps: INR 0.5 - 2 million • Mechanical conveying system: INR 5 - 20 million • Demand-side management system for compressed air optimization: INR 2 - 10 million
	For CPPs	• VFD for boiler feed pump: INR 5 - 10 million • High-efficiency condensate extraction pumps • (CEPs): INR 2 - 3 million • Multistage pressure reduction drag valve: INR 1 - 3 million • Expert optimization system: INR 5 - 10 million • Conversion of AFBC boiler to CFBC boiler: INR 1,000 -1,500 million
	For electrical efficiency improvements and renewable energy (RE) systems	The overall cost of solar photovoltaics (PV) installation (at 30% renewable energy mix) is estimated at INR 60 - 80 million/MW. Investments required for improving energy efficiency in electrical systems: • Installation of energy-efficient motors: INR 8 - 12 million • Replacement of high-pressure sodium vapor/mercury vapor lamps with LEDs: INR 7 - 10 million • Improving power factor of generator: INR 2 - 5 million • Installation of light pipes: INR 0.5 - 2 million • VFD in place of GRR in process fans: INR 5 - 20 million • Use of advanced automation systems like GPRS-based logistics monitoring devices or wireless sensors: INR 5 - 15 million
Installation of WHRS	For WHRS	• Installation of high-efficiency WHRS: INR 80 – 100 million/MW
AFR	For pre-processing and co-processing systems	• Installation of pre-processing and co-processing systems aimed at increased AFR use (capacity up to 100 tpd): INR 500 million – 1 billion
Clinker substitution	For substitution systems	• Installation of clinker substitution systems: INR 5-20 million
	Composite cement	• Production of composite cement (capex cost): INR 5 - 20 million

Accelerating implementation

To facilitate implementation of the roadmap at the plant level, six cement facilities in India undertook resource efficiency studies. IFC supported this initiative.

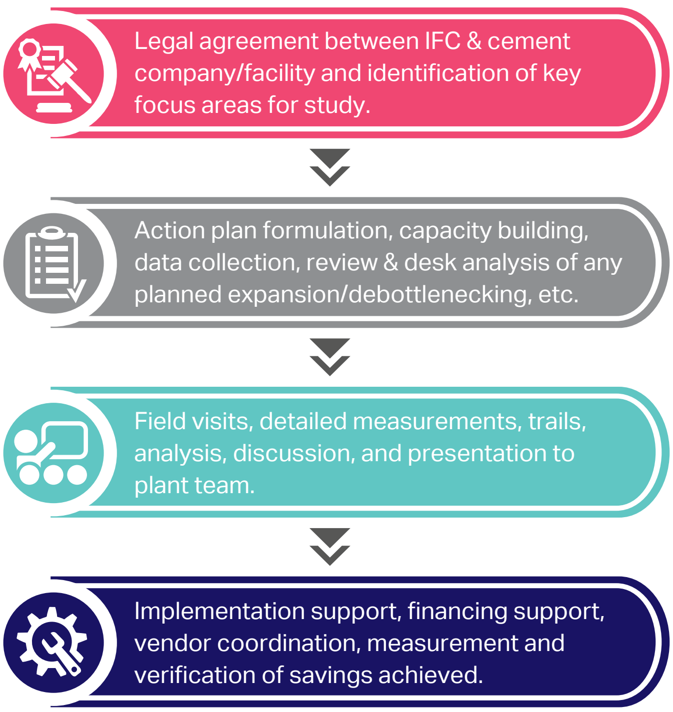
Figure 29: Resource efficiency study locations



Objectives

- Build capacity of plant personnel to identify opportunities for GHG emissions reductions.
- Explore implementation of technology options identified in LCTR.
- Estimate GHG benefits anticipated by adoption of these technologies.
- Estimate cost economics and effectiveness models for reducing carbon emissions.
- Support implementation of identified opportunities by facilitating dialogue with financial institutions.
- Explore feasibility of replicating the recommendations in other company facilities.

Figure 30: Resource efficiency study process flow



Activities undertaken

- Full-day training of the technical team on technology papers identified in LCTR.
- Detailed data collection of power-consuming equipment, production capacities of major equipment, operating parameters and specific power consumption per section.
- Process measurements such as heat and mass balance of kiln and estimation of specific heat consumption; measurement of efficiency of major power consuming equipment such as fans, etc.; power measurements of major electrical energy consumers.
- Analysis of collected data and measurements to develop specific energy saving proposals; extensive laboratory trials conducted to explore the possibility of improving the clinker factor in PPC, PSC.
- Feasibility study to install WHR in the clinkerization line.
- Discussion with plant personnel on identified proposals & presentation on findings.
- Full-day corporate-level training with participation of other company facilities to disseminate learnings.
- Monitoring & verification to estimate reductions in energy and GHG emission for implemented projects.

Table 6: Clinker, cement production and CPP capacity covered by study scope

Name of the facility/unit	Kiln capacity (tpd)	Cement capacity (MTPA)	CPP capacity (MW)
ACC Ltd, Bargarh Cement Works	2,700	1.4	30
Ambuja Cements Ltd, Ambujanagar	12,000	5.5	90
Dalmia Cement (Bharat) Ltd, Dalmiapuram	7,288	3.3	45
CRH-My Home Industries Pvt Ltd, Mellacheruvu	8,100	2.9	75
Shree Cements Ltd, Ras unit Line 7	3,300	1.5	50
UltraTech Cement Ltd, Vikram Cement Works	2,800	4	23
Sonapur Cement Ltd, Nepal	975	0.3	5
Total	37,163	18.9	318

Table 7: Summary of achievements

	Unit	Potential identified	**Reduction achieved** (projects implemented as of February 2017)
Number of energy-saving proposals	Number	350	190
Investment	INR million (USD $ million)	6,084 (95.8)	1257 (19.79)
Electricity savings	MWh/ annum	233,606	111,487
Energy savings	TOE/annum	856,178	235,309
Energy cost savings	INR million/ annum (USD $ million/annum)	1553 (24.46)	543 (8.54)
Total CO_2 emissions reductions from energy-saving projects	tCO_2 per annum	508,762	147,409

Table 8: **Potential identified at seven facilities**

Technology	Electrical & thermal energy-saving potential range identified	CO_2 reduction potential range
Electrical & thermal energy efficiency improvements in preheater & kilns	0.19 - 2.37 kWh/t clinker 3 - 22 kcal/kg clinker	1.25 - 10.3 kgCO_2/t clinker
Latest generation high efficiency clinker coolers	0 - 0.17 kWh/t clinker 8 - 55 kcal/kg clinker	3.6 - 22 kgCO_2/t clinker
Energy efficiency in grinding systems	1.0 - 13.2 kWh/t cement	1.0 - 13.2 kgCO_2/t cement
Energy-efficiency improvements in process fans	0.02 - 8.44 kWh/t cement	0.02 - 8.44 kgCO_2/t cement
Energy efficiency improvements in auxiliary equipment	0.5 - 5.8 kWh/t cement	0.5 - 7.3 kgCO_2/t cement
Energy-efficiency improvements in CPP	5.55 - 47.6 kW/MW	0.01 - 0.21 kgCO_2/kWh
Energy-efficiency improvements in electrical systems	0.2 - 3.4 kWh/t cement	0.2 - 3.4 kgCO_2/t cement
Use of advanced automation systems in cement manufacture	0 - 0.56 kWh/t clinker 0 - 15 kcal/kg clinker	0 - 5.35 kgCO_2/t clinker
Increase fly ash addition in PPC	0 - 13.4 kcal/kg 0 - 0.97 kWh/t	0 -16 kgCO_2/t
Increase slag addition in PSC	0 - 13.5 kcal/kg 0 - 1.0 kWh/t	0 -16 kgCO_2/t
Installation of WHR	0 - 22.7 kWh/t clinker	0 - 22.7 kgCO_2/t clinker

Table 9: **Investment requirements based on technical paper**

Technical paper description	Investment (INR million)	Investment (USD $ million[13])
Electrical & thermal energy-efficiency improvements in preheater & kilns	71.3	1.1
Latest generation high-efficiency clinker coolers	2,562.7	39.4
Energy-efficiency in grinding systems	1,170.7	18.0
Energy-efficiency improvements in process fans	193.0	3.0

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Technical paper description	Investment (INR million)	Investment (USD $ million[13])
Energy-efficiency improvements in auxiliary equipment	105.4	1.6
Energy-efficiency improvements in CPP	1,126.3	17.3
Energy-efficiency improvements in electrical systems	141.8	2.2
Use of advanced automation systems in cement manufacture	3.7	0.1
Increase fly ash addition in PPC	50.0	0.8
Increase slag addition in PSC	0.0	0.0
Installation of WHR	1,183.0	18.2

Table 10: Replication potential in existing plants (industry as a whole)

Technical paper description	Replication potential % of plants (assumption)	Saving (INR million)	Investment required (INR million)	Investment required (USD $ million)	CO_2 reduction potential (MTPA)*
Electrical & thermal energy-efficiency improvements in preheater & kilns	80%	4,264.4	8,528.7	131.2	1.47
Latest generation high-efficiency clinker coolers	80%	7,445.7	29,782.8	458.2	2.98
Energy-efficiency in grinding systems	70%	9,169.7	27,509	423.2	2.04
Energy-efficiency improvements in process fans	60%	4,682.6	9,365.2	144.1	1.04
Energy-efficiency improvements in auxiliary equipment	70%	4,068.2	8,136.5	125.2	0.90
Energy-efficiency improvements in CPP	70%	3,798.8	11,396.3	175.3	1.05
Increased renewable energy use in cement manufacture	60%	114,433	572,164.0	8,802.5	4.61
Energy-efficiency improvements in electrical systems	80%	2,656.8	6,642.0	102.2	0.59

Continued...

[13] Conversion rate USD $1 = INR 65

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Technical paper description	Replication potential % of plants (assumption)	Saving (INR million)	Investment required (INR million)	Investment required (USD $ million)	CO_2 reduction potential (MTPA)*
Use of advanced automation systems in cement manufacture	70%	2,452.1	7,356.4	113.2	0.82
Increased thermal substitution rate in Indian cement plants	90%	19,547.0	78,188	1,202.9	7.86
Reduced clinker factor by increased use of fly ash in PPC	60%	3,350.8	5,026.1	77.3	3.24
Reduced clinker factor by increased use of GBFS in PSC	20%	1,157.2	2,314.4	35.6	0.40
Reduced clinker factor by using low-grade limestone (from 5% filler to 15% filler)	30%	6,130.3	9,195.5	141.5	2.22
Production of composite cement	20%	8,173.8	12,260.6	188.6	1.64
Installation of WHRS	60%	20,768.6	62,306	958.6	4.62
Total		**212,098.7**	**850,171.3**	**13,079.6**	**35.5**

** Assumptions: cement production = 410 Mt (installed capacity); clinker production = 292 Mt; power cost = INR 4.5/kWh; thermal cost = INR 1,000/million kcal*

The above table corresponds to a potential reduction of 35.5 $MtCO_2$ for the entire Indian cement industry based on a national cement production capacity of 410 MTPA.

Studies show good benefits for CO_2 emissions reductions and resource efficiency. The majority of energy savings opportunities identified during the study are economically attractive. Feedback received from the plants indicates that they have implemented 54% of the projects identified. These projects are responsible for 29% of the potential CO_2 emissions reductions identified. The study can be replicated in all other cement plants.

The vision is realistic; yet the targeted reductions are ambitious. The changes required must be practical, realistic and achievable. It is pertinent to note that such ambitions are attainable only with a supportive policy framework and appropriate financial resources invested over the long term. To achieve the efficiency improvements and emissions reduction levels envisioned, government and industry must take collaborative action. It is necessary to create an investment climate that will stimulate the scale of financing required.

Future outlook

Cement, as a sector, has a fundamental role to play in driving long-term sustainable growth in the global economy.

Population growth and urbanization megatrends indicate that global cement production is set to increase between 12-23% by 2050, with an expected three - to six-fold increase in production in India.

However, the growth expectations of the future must factor in an environmentally nimble approach overall. This changing reality poses challenges and opportunities for the cement industry that have previously not been seen in the history of economic growth and infrastructure development.

The cement industry alone accounts for 7% of global CO_2 emissions. Despite increasing efficiencies, the direct carbon emissions as a result of the increased production trends will rise by 4% globally by 2050 according to the RTS. This rising demand is thus creating specific pressure on the cement industry to support the global goal of halving CO_2 emissions by 2050 (up to 212 $MtCO_2$ saved) to limit the rise in global temperatures this century to less than 2°C above preindustrial levels.

India's cement industry performance over the last five years relative to emissions reduction measures, indicates a promising low-carbon future for the cement sector. India's cement industry engages in constructive policy dialogue and deploys technology options that support a low-carbon transition pathway. From improving energy consumption patterns during the production process to increased use of alternative fuels by recovering energy from a range of waste streams, the Indian cement industry is gradually positioning itself to be at the heart of a circular economy.

In 2013, the Low-Carbon Technology Roadmap (LCTR) proposed a bottom-up approach to explore a possible transition pathway based on a least-cost technology analysis for the cement industry to reduce its direct CO_2 emissions. It encompasses policy priorities and regulatory recommendations, investment stimulating mechanisms and technical challenges regarding research, development and demonstration.

This peer reviewed voluntary roadmap containing data from 70% of industry production, a time-bound trajectory of KPIs, information on available technologies (commercialized and under development) and good practices has influenced the low-carbon strategy of most companies in the sector.

The trends in the last five years indicate that achieving the LCTR goals for 2050 would require a combination of technology solutions, supportive policies, public-private collaboration, financing mechanisms and social acceptance. The industry needs a a sustained flow of cumulative investments to achieve the milestones set forth in the roadmap. Policy-makers and industry leaders are required to work together to ensure that the sector's growth becomes a direct function of cost-effective low-carbon technology options in order to be compatible with the long-term climate goals.

The following key trends will drive the low-carbon growth of the sector in the short to medium term:

- Increased investments in use of alternative fuels and enhanced TSR due to favorable policy environments.
- Increased uptake of WHRS – it will become increasingly unviable to run coal-fired CPPs due to high fuel costs, currency depreciation and levies such as the Clean Energy Cess on coal.
- Commercialization of new cements such as LC3.
- Further reductions in clinker factor.
- Development of local CCU solutions based on circular economy principles.

The sector can achieve further emissions savings by considering the overall life cycle of cement, concrete and the built environment. The sector expects that climate change adaptation and mitigation measures coupled with favorable policy drivers[14] will increase concrete use in India. While the sector anticipates that the pace of growth in production in the country will slow down between 2030 and 2050, cement demand will continue to increase. By optimizing the use of concrete in construction and thereby maximizing the design life of buildings and infrastructure, encouraging reuse and recycling, reducing waste and benefiting from concrete's properties to minimize energy needs for the heating and cooling of buildings, the cement sector and its value chains are on the path to a low-carbon circular future.

Strategic partnership between the Global Cement and Concrete Association (GCCA) and WBCSD

The Global Cement and Concrete Association (GCCA) was formed in January 2018 by seven major cement companies, including several WBCSD CSI members. The GCCA will work on cement and concrete sector sustainability issues.

The WBCSD will transfer the work that CSI carried out to GCCA as of 1 January 2019. The two organizations have set up a strategic partnership to facilitate the sustainable development of the cement and concrete sectors and their value chains. The new partnership aims to create synergies between work programs to benefit both organizations and their respective member companies.

To harmonize efforts, CSI in India, being a unique example of business collaboration and national action, will join with the GCCA on the same date to become GCCA India.

WBCSD has been pleased to foster and support the CSI in India, which has a track record to be proud of, and is committed to ensuring the program's smooth transition and a successful future for GCCA in India.

[14] The Union Budget allocates USD $92.22 billion to infrastructure development in 2018-19 compared to USD $76.31 billion in 2017-18. The government's infrastructure push combined with the Housing for All strategy, Smart Cities Mission and Swachh Bharat Abhiyan are the major catalysts in facilitating the cement sector's sustainable growth in India.

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Annexes

Annex A: scenarios used in the report

The International Energy Agency (IEA) developed the scenarios referred to in the report within the framework of modelling and analysis in the IEA Energy Technology Perspectives (ETP) project.

According to the Intergovernmental Panel on Climate Change's Fifth Assessment Report published in 2014, the 2-degree Celsius Scenario (2DS) sets out an energy system pathway and a CO_2 emissions trajectory consistent with at least a 50% chance of limiting the average global temperature increase to 2°C by 2100. The world will need to reduce annual energy sector CO_2 emissions by around 60% from current levels by 2050, with cumulative carbon emissions of around 1,170 Gt CO_2 between 2015 and 2100 (including industrial process emissions). To stay within this range, CO_2 emissions from fuel combustion and industrial processes must continue their decline after 2050, and the energy system must reach carbon neutrality by 2100. The 2DS represents an ambitious and challenging transformation of the global energy system that relies on a substantially strengthened response compared to current efforts according to the Technology Roadmap: Low-Carbon Transition in the Cement Industry published by CSI in partnership with IEA in 2018.

The 6-degree Celsius Scenario (6DS) is largely an extension of current trends, with no effort on the part of government, industry or the general public to curb emissions. In the absence of efforts to stabilize atmospheric concentrations of GHGs, the average global temperature rise was projected at that time to be at least 6°C in the long term. This scenario was used in 2013 as the baseline in the Technology Roadmap: Low-Carbon Technology for the Indian Cement Industry 2013.

The Reference Technology Scenario (RTS) serves as the updated baseline for the recent Global Cement Roadmap 2018. It considers energy consumption trends, as well as commitments by countries to limit carbon emissions and improve energy efficiency, including nationally determined contributions pledged under the Paris Agreement. The RTS represents a considerable shift from a business-as-usual approach with no meaningful climate policy response. Efforts made under the RTS would result in an average temperature increase of 2.7°C by 2100, at which point temperatures are unlikely to have stabilized and would continue to rise.

The scenarios are based on technologies that are commercially available or are in the demonstration phase. The minimization of overall production costs among available technologies as they reach successful commercialization over time result in the industrial technological shifts analyzed. The scenarios assume that industries overcome non-technical barriers to the deployment of new technologies, including social acceptance, ineffective regulatory frameworks and information deficits. The analysis does not assess the likelihood that these assumptions will come true but highlights that ambitious CO_2 emissions reductions require the collective contributions of all stakeholders: governments, industry and society. These scenarios are not predictions. They are internally consistent analyses of cost-optimal pathways that may be available to meet energy policy objectives, given a certain set of techno-economic assumptions.

Annex B: glossary

Aggregate: Material used in construction, including sand, gravel and crushed stone.

Alternative fuels: Products from full or partial biogenic origin or from fossil fuel origin and not classified as traditional fossil fuels, which are used as a source of thermal energy.

Biomass: Any organic (i.e., decomposing) matter derived from plants or animals available on a renewable basis, including wood and agricultural crops, herbaceous and wood energy crops, municipal organic wastes and manure.

Blended cement: Portland cement (PC) mixed with other constituents as well as clinker.

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 or crushed stone and water to make concrete. Although cement qualities are defined by national standards, there is no worldwide, harmonized definition or standard. In the World Business Council for Sustainable Development (WBCSD) Cement Sustainability Initiative (CSI) protocol and the Getting the Numbers Right database, "cement" includes all hydraulic binders that are delivered to the final customer. That is, it includes all types of Portland cement, composite and blended cements, and ground granulated slag and fly ash delivered to the concrete mixers but excludes clinker.

Cementitious product: Total of all cements and clinker produced by a cement company, excluding the clinker purchased from another company and used to make cement. The precise definition of cementitious product in this context is according to the WBCSD-CSI cement protocol (2011). Cement is the cementitious product when the net balance of clinker sold and purchased is zero.

Clinker: An intermediate product in cement manufacturing and the main substance in cement. It is the result of the calcination of limestone in the kiln and subsequent reactions caused through burning.

Clinker-to-cement ratio: Total clinker consumed divided by the total amount of cement produced.

Clinkerization process: Process of converting raw meal into clinker. The preheating of the raw meal takes place in preheater cyclones fitted with a pre-calciner fired coal. The calcination of the material begins during this stage, changing its phase to the oxide phase for each component to be ready for the burning process. The burning phase takes place in a rotary kiln. The clinker temperature in the kiln burning zone has to reach 1,500°C and then it is cooled in a cooler by air.

Clinker cooler: Coolers are essential parts of rotary kiln systems. Clinker leaves the kiln at 1,200°C or more. Clinker at this temperature has high heat content and must be cooled. The clinker is cooled in a cooler by supplying ambient air. The essential characteristic of a grate cooler is a layer of clinker spread on a more-or-less horizontal perforated grate, through which cold air is blown.

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. It is used to increase the surface area of solids in industrial processes.

Concrete: Material comprising cement, sand and gravel or other fine and coarse aggregate.

Co-processing: The use of waste materials in industrial processes (e.g., cement) as substitutes for fossil fuels or raw materials.

Direct carbon dioxide (CO_2) emissions: CO_2 emissions that are generated and released in the cement production process.

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

Electricity intensity of cement: consumption of electricity in cement production, including electricity use in the production of the consumed clinker in the kiln, divided by the cement and substitute production.

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

Geopolymer cement: 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.

Gross direct CO_2 emissions: Total direct CO_2 emissions from the cement production process including CO_2 related to the combustion of wastes based on fossil fuels but excluding those from biogenic wastes.

Kiln: Cement kilns are used for the pyro-processing stage of manufacture of Portland and other types of hydraulic cement, in which calcium carbonate reacts with silica-bearing minerals to form a mixture of calcium silicates. The kiln is a log cylindrical shell, 2.5 to 5 meters in diameter and 55 to 70 meters in length. The inner side of the kiln is lined with refractory bricks.

Oxy-fuel: The combustion of fuels with oxygen instead of air.

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

Portland cement (PC): The most-common type of cement, consisting of over 90% clinker and about 5% gypsum.

Pozzolana: A material that exhibits cementitious properties when combined with calcium hydroxide.

Pre-calciner: A system that comes before the rotary kiln in the cement manufacturing process and where most of the limestone calcination is accomplished, thus making the process more energy-efficient.

Preheater: Used in dry kiln cement production plants to heat the raw mix and drive off carbon dioxide and water before it is fed into the kiln.

Process CO_2 emissions: CO_2 generated because of chemical reactions from carbon contained in raw materials.

Recarbonation: The chemical reaction in a natural process by which carbon dioxide in the ambient air penetrates and reacts with hydration products.

Sectoral approach: A combination of policies and measures developed to enhance efficient, sector-by-sector GHG gas mitigation within the United Nations Framework Convention on Climate Change (UNFCCC). Producers and their host country governments adopt a set of emissions goals, which may vary by country, or take other coordinated action to help combat climate change.

Thermal energy intensity of clinker: Total heat consumption of kilns divided by clinker production.

Traditional fuels: Fossil fuels defined by the guidelines of the Intergovernmental Panel on Climate Change, including mainly coal, petcoke, lignite, shale petroleum products and natural gas.

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

Annex C: acronyms, abbreviations and units of measurement

2DS: 2 degrees Celsius Scenario
6DS: 6 degrees Celsius Scenario
AFBC: atmospheric fluidized bed combustion
AFR: alternative fuels and raw materials
APC: auxiliary power consumption
BAU: business-as-usual
BIS: Bureau of Indian Standards
BOOT: build-own-operate-transfer
CAGR: compound annual growth rate
CCS: carbon capture and storage
CCS & U: carbon capture, storage and use
CCU: carbon capture and use
CEP: condensate extraction pump
CFBC: circulating fluidized bed combustion
CFD: computational fluid dynamics
CII: Confederation of Indian Industry
CMA: Cement Manufacturers Association
CPCB: Central Pollution Control Board
CPP: captive power plant
CSI: Cement Sustainability Initiative
CSP: concentrated solar power
DC: designated consumers
ECRA: European Cement Research Academy
EMS: energy management systems
ESCERTs: Energy Saving Certificates
ETP: effluent treatment plant
FAKS: fluidized-bed advanced cement kiln system
FDI: foreign direct investment
GBFS: ground blast furnace slag
GCCA: Global Cement and Concrete Association
GCF: Green Climate Fund
GHG: greenhouse gas
GNR: Getting the Numbers Right
GRR: grid rotor resistance
HT: high temperature
HPGR: high-pressure grinding roller
HWM: hazardous waste management
IEA: International Energy Agency
IEC: integrated energy contracts
IFC: International Finance Corporation
KPI: key performance indicator
LC3: limestone calcined clay
LCTR: Low-Carbon Technology Roadmap
LSF: lime saturation factor
MIC: mineral components
MCC: motor control centers
MDB: multilateral development bank
MoEFCC: Ministry of Environment Forest and Climate Change
MoHUA: Ministry of Housing and Urban Affairs
MSW: municipal solid waste
NAPCC: National Action Plan on Climate Change
NCB: National Council for Cement and Building Materials
NMEEE: National Mission on Enhanced Energy Efficiency
NOx: nitrogen oxides
ODS: ozone depleting substances
OPC: ordinary Portland cement
PAT: Perform Achieve Trade scheme
PCB: polychlorinated biphenyls
PCC: pollution control committee
PoP: persistent organic pollutants
PPC: Pozzolana Portland cement
PPP: public-private partnership
PSC: Portland slag cement
PV: photovoltaics
R&D: research and development
RDF: refuse-derived fuel
RE: renewable energy
RPO: renewable purchase obligation
RTS: Reference Technology Scenario
SDC: Swiss Development & Cooperation Agency
SDG: Sustainable Development Goal
SEC: specific energy consumption
SPCB: State Pollution Control Board
SPRS: slip power recovery systems
SWM: solid waste management
TARA: Technology and Action for Rural Advancement
TSR: thermal substitution rate
ULB: urban local bodies
UNFCCC: United Nations Framework Convention on Climate Change
VFD: variable frequency drives
VRM: vertical roller mill
WBCSD: World Business Council for Sustainable Development
WHR: waste heat recovery
WHRS: waste heat recovery system

Units of measurement

°C: degree Celsius
Gt: gigatonne (10^9 tonnes)
GJ: gigajoule
GWh: gigawatt hour (10^9 watt hour)
INR: indian rupee
Kcal: kilocalorie (10^3 calories)
Kg: kilogram (10^3 gram)
kW: kilowatt (10^3 watt)
kWh: kilowatt hour (10^3 watt hour)
MJ: megajoule (10^6 joules)
Mt: million tonnes (10^6 tonnes)
MTOE: million tonnes oil equivalent
MTPA: million tonnes per annum
MW: megawatt (10^6 watt)
t: tonne
tpd: tonnes per day
USD $: United States Dollar

Contributing organizations

wbcsd

World Business Council for Sustainable Development (WBCSD)

The World Business Council for Sustainable Development (WBCSD) is a global, CEO-led organization of over 200 leading businesses and partners working together to accelerate the transition to a sustainable world. WBCSD helps its member companies become more successful and sustainable by focusing on the maximum positive impact for shareholders, the environment and societies.

WBCSD member companies come from all business sectors and all major economies, representing combined revenues of more than USD $8.5 trillion and 19 million employees. The WBCSD global network of almost 70 national business councils gives members unparalleled reach across the globe. WBCSD is uniquely positioned to work with member companies along and across value chains to deliver impactful business solutions to the most challenging sustainability issues.

Together, we are the leading voice of business for sustainability: united by our vision of a world where more than 9 billion people are all living well and within the boundaries of our planet, by 2050.

www.wbcsd.org

Cement Sustainability Initiative

Cement Sustainability Initiative (CSI)

The Cement Sustainability Initiative (CSI) is a global effort by 24 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 large multinational companies to small local producers.

All CSI members have integrated sustainable development into their business strategies and operations, as they seek strong financial performance with an equally strong commitment to social and environmental responsibility. The CSI is an initiative of the World Business Council for Sustainable Development (WBCSD). The CSI is one of the largest global sustainability projects ever undertaken by a single industry sector.

www.wbcsdcement.org

Collaborator

iea International Energy Agency

International Energy Agency (IEA)

The International Energy Agency (IEA) examines the full spectrum of energy issues including oil, gas and coal supply and demand, renewable energy technologies, electricity markets, energy efficiency, access to energy, demand side management and much more. Through its work, the IEA advocates policies that will enhance the reliability, affordability and sustainability of energy in its 30 member countries, 8 association countries and beyond.

The four main areas of IEA focus are:

- **Energy Security:** Promoting diversity, efficiency, flexibility and reliability for all fuels and energy sources.
- **Economic Development:** Supporting free markets to foster economic growth and eliminate energy poverty.
- **Environmental Awareness:** Analysing policy options to offset the impact of energy production and use on the environment, especially for tackling climate change and air pollution.
- **Engagement Worldwide:** Working closely with association and partner countries, especially major emerging economies, to find solutions to shared energy and environmental concerns.

www.iea.org

Partners

Confederation of Indian Industry (CII)

The Confederation of Indian Industry (CII) works to create and sustain an environment conducive to the development of India, partnering industry, Government, and civil society, through advisory and consultative processes.

CII is a non-government, not-for-profit, industry-led and industry-managed organization, playing a proactive role in India's development process. Founded in 1895, India's premier business association has around 9000 members, from the private as well as public sectors, including SMEs and MNCs, and an indirect membership of over 300,000 enterprises from around 265 national and regional sectoral industry bodies.

As a developmental institution working towards India's overall growth with a special focus on India@75 in 2022, the CII theme for 2018-19, India RISE: Responsible. Inclusive. Sustainable. Entrepreneurial emphasizes Industry's role in partnering Government to accelerate India's growth and development. The focus will be on key enablers such as job creation; skill development; financing growth; promoting next gen manufacturing; sustainability; corporate social responsibility and governance and transparency.

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www.greenbusinesscentre.com

IFC International Finance Corporation WORLD BANK GROUP

Creating Markets, Creating Opportunities

International Finance Corporation (IFC)

IFC - a sister organization of the World Bank and member of the World Bank Group - is the largest global development institution focused on the private sector in emerging markets. We work with more than 2,000 businesses worldwide, using our capital, expertise, and influence to create markets and opportunities in the toughest areas of the world. In fiscal year 2018, we delivered more than $23 billion in long-term financing for developing countries, leveraging the power of the private sector to end extreme poverty and boost shared prosperity.

www.ifc.org

CEMENT MANUFACTURERS ASSOCIATION

Cement Manufacturers Association (CMA)

The Cement Manufacturers Association (CMA) is the apex representative body of large cement manufacturers in India. CMA is a unique platform as it represents both the private and the public sector cement companies. It is the consolidated voice of the Indian Cement Industry on matters impacting its business such as environmental, logistics, taxation, alternate fuels, sustainability, innovation, waste consumption, etc., and represents the Indian Cement Industry at national and international fora.

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