SHAKTI SUSTAINABLE ENERGY FOUNDATION

Alliance for an Energy Efficient Economy

Reducing Cement Sector emissions

Approaches to reduce the demand of Cement from Construction

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Reducing Cement Sector Emissions: Approaches to reduce the demand of Cement from Construction

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About Alliance for an Energy Efficient Economy:
Alliance for an Energy Efficient Economy (AEEE) is a policy advocacy and energy efficiency market enabler with a not-for-profit motive.

About Shakti Sustainable Energy Foundation:
Shakti Sustainable Energy Foundation seeks to facilitate India's transition to a sustainable energy future by aiding the design and implementation of policies in the following areas: clean power, energy efficiency, sustainable urban transport, climate change mitigation, and clean energy finance.

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Contents

Acronyms

°C	Degree Celsius
3-D	Three-Dimensional
AMRUT	Atal Mission for Rejuvenation and Urban Transformation
BIS	Bureau of Indian Standards
BMTPC	Building Materials and Technology Promotion Council
BRPC	Belite Rich Portland Cement
BYF	Belite-Ye'elimite-Ferrite
C&D	Construction & Demolition
C_2S	Alite
C_3A	Belite
C_3S	Tricalcium Aluminate
CAGR	Compound annual growth rate
CBRI	Central Building Research Institute
CCS	Carbon Capture and Storage
CCSC	Carbonatable calcium silicate cements
CEEW	Council on Energy, Environment and Water
CIDEM	Centro de Investigación y Desarrollo de Estructuras y Materiales
CII	Confederation of Indian Industry
CLT	Cross Laminated Timber
CMA	Cement Manufacturer's Association
CO_2	Carbon Dioxide
CPWD	Central Public Works Department
CSA	calcium sulfoaluminate
CSI	Cement Sustainability Initiative
CSIR	Council of Scientific & Industrial Research
CSIR-NML	Council of Scientific & Industrial Research - National Metallurgical Laboratory
DfD	Design for Deformation
DIPP	Department for Promotion of Industry and Internal Trade
EE	Energy Efficiency
EERI	Earthquake Engineering Research Institute
FY	Fiscal Year
GC	Geopolymer concrete
GDP	Gross domestic product
GGBFS	Ground Granulated Blast-Furnace Slag
GHG	Green House Gas
GIS	Geographic Information System
GJ	Giga Joule
GOI	Government of India
IBEF	India Brand Equity Foundation

IBM	Indian Bureau of Mines
IEA	International Energy Agency
IITGN	Indian Institute of Technology Gandhinagar
IIT	Indian Institute of Technology
IS	Indian Standard
kg	Kilogram
KWh	Kilo Watt hour
LD Slag	Linz-Donawitz Slag
m^3	Cubic meter
mm	Milli meter
MoEFCC	Ministry of Environment, Forest and Climate Change
MoHUA	Ministry of Housing and Urban Affairs
MOMS	Magnesium Oxide based cements derived from magnesium silicates
MSW	Municipal Sewage Waste
MT	Million tons
Mtoe	Million tons of oil equivalent
NCCBM	National Council for Cement and Building Materials
NITI Aayog	National Institution for Transforming India Aayog
NTPC	National Thermal Power Corporation
OPC	Ordinary Portland Cement
PAT	Perform Achieve and Trade
PMAY	Pradhan Mantri Awas Yogana
PPC	Portland Pozzolana Cement
PSC	Portland Slag Cement
RC	Reinforced concrete
RDF	Refused Derived fuel
SC	Smart Crusher
SCMs	Supplementary cementing materials
SDC	Swiss Agency for Development and Cooperation
SPCBs	State Pollution Control Boards
TARA	Technology and Action for Rural Advancement
PPs	Thermal Power Plants
TSR	Thermal substitution rate
TU Delft	Technical university Delft
ULBs	Urban Local Bodies
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States Dollar
WBCSD	World Business Council for Sustainable Development
WHRS	Waste Heat Recovery Systems

Executive Summary

India's journey towards becoming a robust economy is largely dependent on the growth of its industrial sector and cement is the most produced commodity of this sector. With an annual installed capacity of 545 million tons in 2018-2019, the Indian cement industry is the second-largest producer of cement, after China. Moreover, the demand of cement in India is expected to grow, driven by schemes like Smart city mission, Housing for all, Bharatmala Pariyojana, Pradhan Mantri Gram Sadak Yojana, Urban Transport Metro Rail Projects etc. This high demand for cement also associates with it, the environment damaging Green-House Gas (GHG) emissions. Cement Industry is among the Hard-to-abate industrial sectors in India as, in spite of the noteworthy progress by the Indian cement industry in enhancing energy efficiency, GHG emissions from the cement sector are still significantly higher (187 million tons of CO_2e in 2015-16) (GHG Platform India, 2016). To achieve the climate change mitigation targets, in-line with the Paris Agreement which attempts to limit the global temperature increase by 2°C at the end of this century, there is an urgent need to explore other opportunities (beyond energy efficiency) to limit the GHG emission from India's cement industry.

The GHG emissions in cement production are due to electricity use, combustion of fossil fuel (energy use), and from the conversion process of limestone into lime (industrial process and product use) which contributes to 13%, 31%, and 56% respectively (CII, 2010). The process emissions having a larger contribution, can be reduced by reducing the clinker content of the cement. In recent years, a lot of research and development is happening to develop such low clinker cements like LC^3, composite cements, geopolymer binders, belite rich cements and other novel cements. Out of these options, composite cement, having 56% CO_2 reduction potential as compared to OPC, is already under production, while LC^3 having 30% CO_2 reduction potential is in the final stages of development in India. Moreover, geopolymer concrete, having 80% CO_2 reduction potential, is in the early stages of development. All the other options (discussed in the report) are currently at various stages of research.

The use of Secondary Cementitious Materials (SCMs) like fly ash, slag, pond ash, fillers (low-grade limestone) etc., can be used to replace the clinker in the final cement mix and thereby minimizing the emissions. Moreover, recovering cement from the Construction and Demolition (C&D) waste through technologies like "SmartCrusher bv" will help in reducing the demand for fresh cement. It enables segregation of hydrated cement, unhydrated cement, sand and gravel from the C&D waste. Further, design optimization and new construction techniques can help in reducing the demand for cement in the construction projects. Design techniques like bubble deck, voided concrete slab systems can reduce cement requirement significantly without impacting the slab strength. The design for deformation strategy, enables designing buildings in a modular way so that its components can be easily disassembled and used in other applications when the building reaches to its end of life. Also, the use of confined masonry and timber in the building construction has a good potential for reducing the cement demand.

Hence, to mitigate the emissions from the Indian cement industry, there are several possible measures which has been discussed in this report. However, there is a need to further study the feasibility of each of the available alternate low carbon material options, substituting materials, and design & construction optimization strategies in a more detailed manner. Moreover, there is also a need for development of standards, creating awareness among the user community for quicker adoption, and creating an ecosystem for the faster replication.

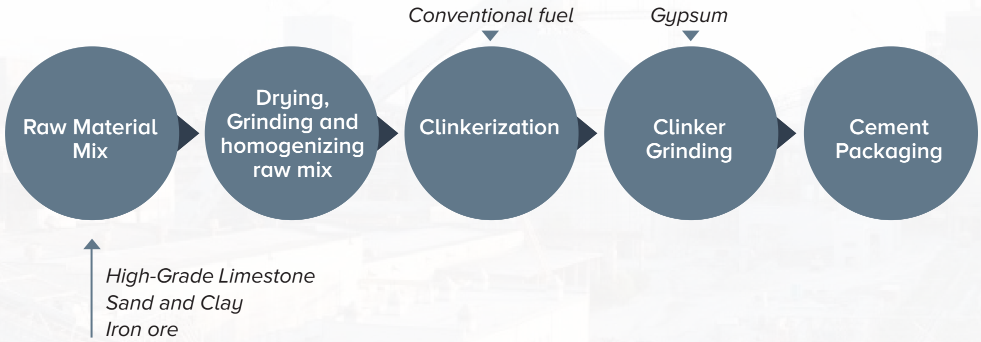
1. Overview: Indian Cement Industry

India's journey towards becoming a 5-trillion USD economy by 2025 is largely dependent on the growth of its industrial sector as it contributes 29.6% in the India's gross value addition (Ministry of finance, 2020). Cement, the most used commodities in the construction sector, contributed to around 30% of the total GHG emissions from the Indian industrial sector in 2016 (CEEW, 2019). The demand for cement is expected to grow in the coming years, due to the introduction of various schemes like smart city mission, Housing for all, and launch of several infrastructure projects among others (CMA, 2019). Therefore, along with growing demand, comes the growing GHG emissions associated with the production of cement. To achieve the country's climate change mitigation targets of reducing the GHG emission intensity of its GDP by 33%-35% (taking 2005 as the base year) (MoEFCC, 2018) and to restrict the global temperature change in the century by 2°C (UNFCCC, 2015), there is an urgent need to reduce these emissions. Before going to the discussion on different ways of mitigating GHG emissions from the cement industry, it is crucial to understand the different processes involved in the cement production and different sources of emissions from the cement industry.

1.1. Cement Production Process

Production of cement starts with the mining and extraction of various raw materials like High-Grade limestone (rich in calcium), clay (rich in silicon), and sand, etc. After extraction, these raw materials are stored in an open yard storage. Figure 1, shows the process flow in a typical conventional cement production plant.

FIGURE 1: Conventional cement production process



Initially, the raw material mix is prepared by grinding and mixing the raw materials in the required proportions. The prepared raw mix is then passed through various stage of Clinkerization process. Before entering into the kiln (for clinker production), the raw feed is passed through the pre-heater stage, where it is heated up to 800°C and most of the limestone is decomposed. Inside the kiln where the temperature is around 1450°C -1500°C, the raw feed breaks into Alite (C_3S), Belite (C_2S), Tricalcium aluminate (C_3A), etc. and the composition of these materials is called clinker. The clinker formed at the exit of the kiln is cooled at 200°C by passing it through the cooler. Once the clinker gets cooled, it is ground and mixed in appropriate proportions with gypsum or fly ash or slag, as per the requirement of the final product. This final product (Cement) is then packed in 50 kg bags and are ready to be dispatched.

1.2. Production and Consumption of cement in India

With an annual installed capacity and production of 537 million tons and 337 million tons (2018-2019) respectively (DIPP, 2020), the Indian cement industry is the second-largest producer of cement, after China and accounts for 8% of the total installed capacity worldwide (CMA). Figure 2, shows the cement consumption trend in India from 2015 to 2019 and the estimated cement consumption till 2025 (IBEF, 2020).

Cement consumption in India has increased at a CAGR of 5.8% from 2012-2019. This demand is further expected to increase in the future, as it is clear from the government's increasing efforts on the developing infrastructure (with the introduction of schemes and projects such as smart city mission, AMRUT, Metro rail development projects, dedicated freight corridors and port development etc.) and construction projects (housing for all in urban and rural areas), where cement is the primary construction material. The per-capita consumption of cement in India is 240 kg, which is well below the global consumption of 530 kg (DIPP, 2020). Housing and real estate, infrastructure, commercial and industrial development, are the major cement consuming sectors in India.

FIGURE 2: Consumption trend of Indian cement sector

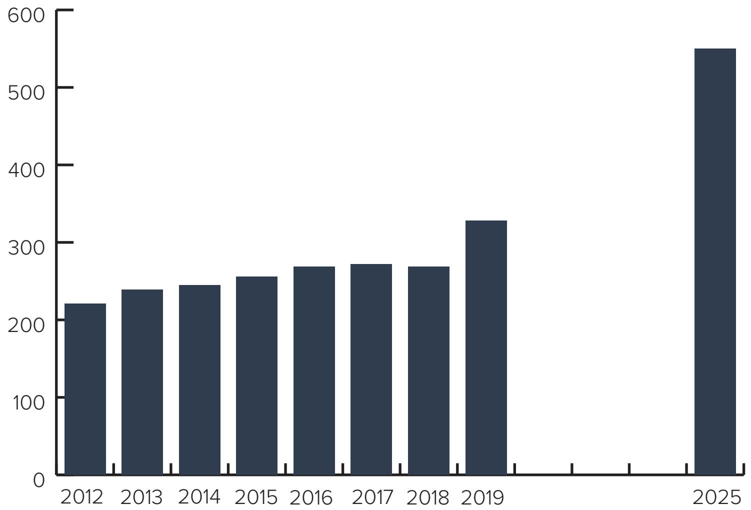


FIGURE 3: Sector-wise cement consumption (CARE-Ratings, 2019)

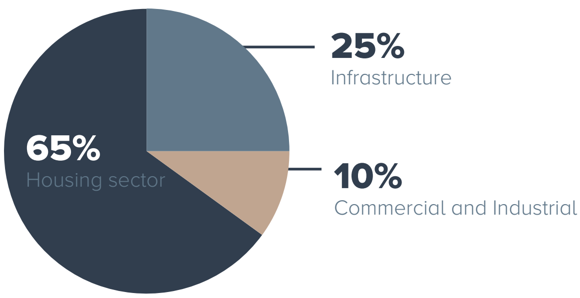


Figure 3 shows the sector-wise consumption of cement in India in FY 2019-2020.

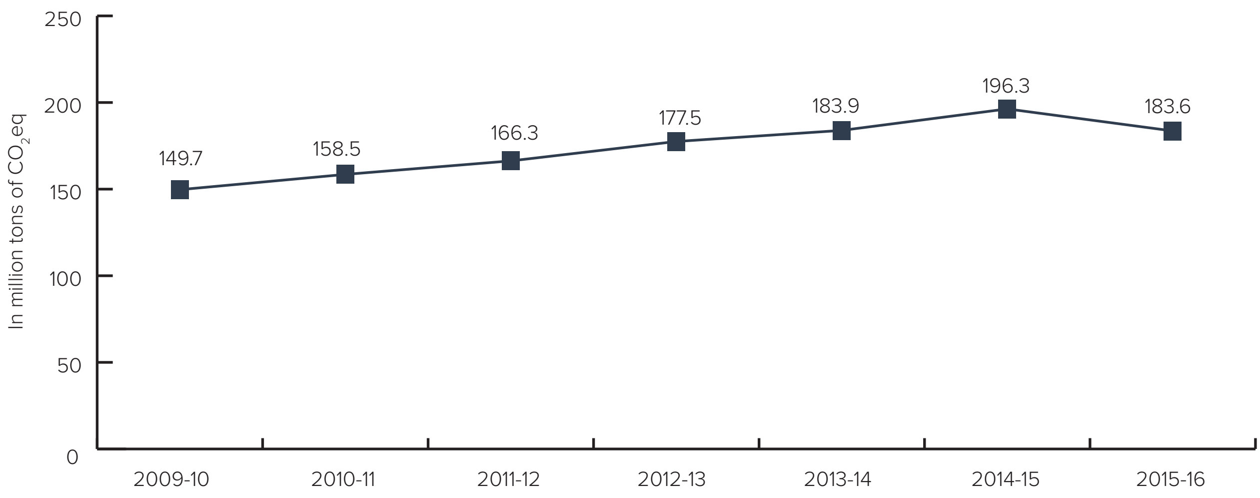
From Figure 3, it can be seen that the Housing sector, which includes residential flats, individual flats, and rural housing, is the highest consumer of cement among all the other sectors. Infrastructure development (includes, roads, railways, airports, ship ports etc.) is the second-largest contributor in the cement demand followed by commercial construction and industrial construction. Housing along with commercial & industrial construction combinedly contribute to 75% of the total country's cement demand.

1.3. Sources of GHG emissions from the cement sector

GHG emissions from the Indian cement industry has a considerable amount of share in the overall national emissions (8% in 2015). Also, the average emission intensity of India's cement industry was 0.576 tons of CO_2 per tonne of cement as on 2018 (GNR Project), whereas the global average carbon intensity for cement production was 0.634 tonne of CO_2 per tonne of cement in 2018 (GNR Project).

The historic trend of emissions from the cement industry is shown in Figure 4.

FIGURE 4: **GHG emissions trend from Indian cement sector (2009-2016) (GHG Platform India, 2017)**

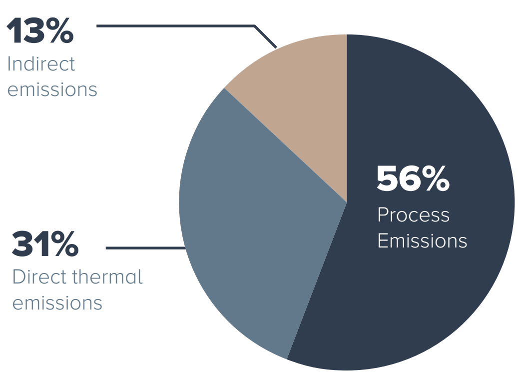


From Figure 4, it can be observed that the GHG emissions from the Indian cement industry are rising continuously from 2009 to 2015 and there is a dip in the curve from 2014-15 to 2015-16, which could be due to the Perform, Achieve and Trade (PAT) scheme and various energy efficiency interventions adopted in the past few years by the Indian cement industry.

Further, the breakdown of emissions from the cement sector includes process emissions (calcination of limestone into calcium oxide), direct thermal emissions (combustion of fuel), and indirect emissions (due to electricity consumption in the grinding of raw materials, fuel preparation, and clinker production). Figure 5, shows the contribution of various sources of GHG emissions in the cement industry.

From Figure 5, it can be observed that the process emissions have the highest contribution to the total GHG emissions followed by thermal energy consumption.

FIGURE 5: **GHG emissions from various emitting sources (*CII, 2010*)**



2. Motivation

To achieve the climate change mitigation targets, in-line with the Paris Agreement which attempts to limit the global temperature increase by 2°C at the end of this century, there is a need to reduce the emissions from the cement sector. In the past few years, with the help of the PAT scheme, introduced by the Government of India (GOI), the Indian cement industry has overachieved its energy efficiency targets and is now being seen as the most energy-efficient globally. The specific energy consumption of the Indian cement industry is listed below in Table 1.

TABLE 1: Performance of Indian Cement industry in Energy efficiency

Particulars	Global Average	India Best	India Average
Specific Thermal Energy consumption (GJ/tonne of clinker)	3.5	2.83	3.1
Specific Electrical Energy Consumption (kWh/tonne of cement)	91	64	80

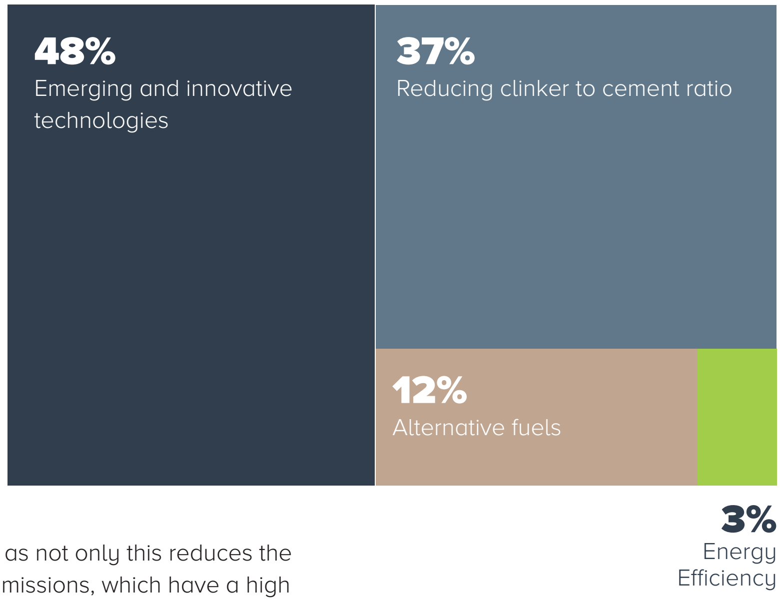
Source: CMA

Although, significant progress has been made by the Indian cement industry in enhancing energy efficiency, yet GHG emissions from the cement sector are still significantly higher (187 million tons of CO_2e in 2015-16) (GHG, 2016). This indicates that the potential of energy efficiency, in reducing the emissions from cement production is low, and therefore, it is necessary to find ways to limit the GHG emission by exploring other methods beyond energy efficiency.

The International Energy Agency (IEA), Cement Sustainability Initiative (CSI), and World Business Council for Sustainable Development (WBCSD), has prepared a document on technology roadmap for low-carbon transition of the cement industry (by 2050). This document identifies various carbon emission reduction levers and estimates the decarbonization potential of these levers under a 2-degree scenario (2DS) (IEA, 2018), as presented next.

From Figure 6, it can be observed that emerging and innovative technologies like carbon capture and storage (CCS), renewable energy technologies, and others have the highest potential, but either they are in the research stage, or not widely adopted by the cement industry. The uptake of renewable energy technology depends on various factors like land requirement, electricity prices in that location, the initial investment required, etc. Similarly, for the CCS, a detailed techno-economic feasibility is needed as its deployment will have a significant impact to the cost of cement production.

FIGURE 6: **Decarbonization potential of different techniques (IEA, 2018)**



The other option i.e. reduction in the clinker to cement ratio has the second-highest potential for emission reduction. This is being considered as a high priority now, as not only this reduces the direct thermal emissions but also the process emissions, which have a high contribution in the total GHG emissions of the cement industry and cannot be addressed by EE measures. Currently, there has been good progress in terms of identifying new alternate materials with lower clinker content and therefore it holds a high priority in the near future.

The alternative fuels generally consist of municipal sewage waste (MSW), biomass, hazardous waste, etc. In recent years, the Indian cement industry has started using alternative fuels to further cut down emissions. The amount of alternative fuel used by the cement industry is defined by the Thermal Substitution Rate (TSR), which refers to the percentage of alternative fuel used to replace fossil fuels (CMA, 2020). From the TSR level of 4% in 2016 (was 0.6% in 2010), the Indian cement industry targets to achieve 25% TSR by 2025 and 30% by 2030 (CMA, 2020). However, there are several challenges associated like the segregation of MSW, collection of biomass, handling of hazardous waste etc.

As seen in figure 6 energy-efficient technologies can contribute possibly 3% additional emission reduction in the cement sector. To realize the further potential in EE, various interventions like waste heat recovery, uptake of high energy-efficient coolers, grinding systems, use of VFD in process fans are being taken up. A more prominent use of waste heat recovery systems (WHRS) in the cement plants will help to recover the heat from the cooler and utilize it for other applications, like process heating and electricity generation.

However, none of the previous studies explore the cement demand reduction in construction as an opportunity to minimize cement sector emissions. There are some promising low carbon alternate cements which have undergone successful pilot demonstration, while others are in the development stage. Similarly, circular economy including utilization of industrial by-products (like supplementary cementitious materials (SCMs)) in cement manufacturing and also reuse of C&D waste in new buildings holds a good potential to reduce the fresh cement demand. Further, design and construction optimization can help in lowering the cement requirement without compromising on the structural stability of the infrastructure. All these measures are discussed in more detail in the next sections.

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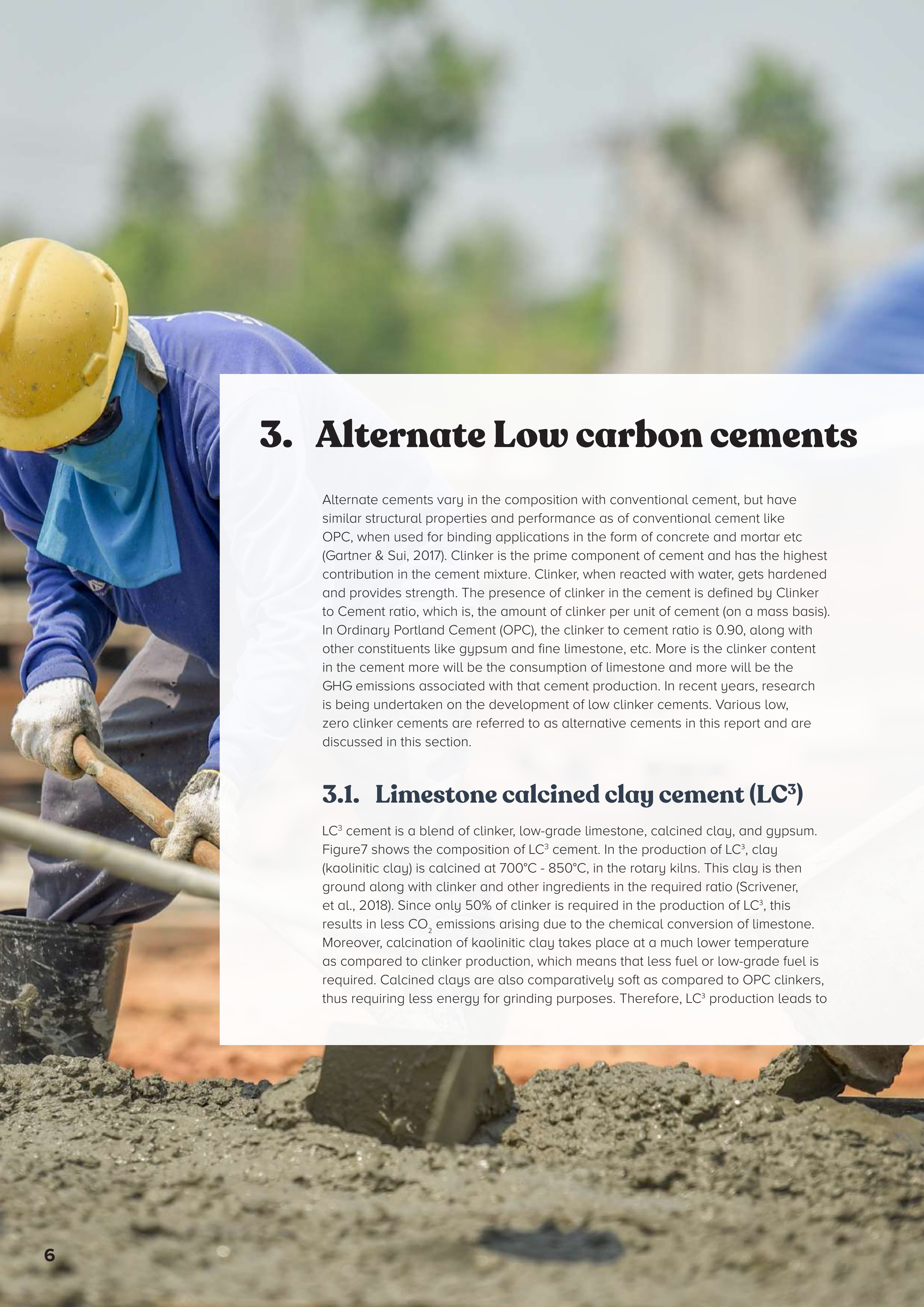


3. Alternate Low carbon cements

Alternate cements vary in the composition with conventional cement, but have similar structural properties and performance as of conventional cement like OPC, when used for binding applications in the form of concrete and mortar etc (Gartner & Sui, 2017). Clinker is the prime component of cement and has the highest contribution in the cement mixture. Clinker, when reacted with water, gets hardened and provides strength. The presence of clinker in the cement is defined by Clinker to Cement ratio, which is, the amount of clinker per unit of cement (on a mass basis). In Ordinary Portland Cement (OPC), the clinker to cement ratio is 0.90, along with other constituents like gypsum and fine limestone, etc. More is the clinker content in the cement more will be the consumption of limestone and more will be the GHG emissions associated with that cement production. In recent years, research is being undertaken on the development of low clinker cements. Various low, zero clinker cements are referred to as alternative cements in this report and are discussed in this section.

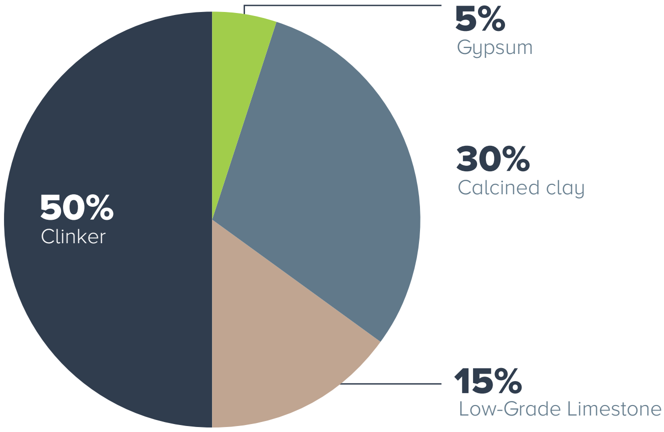
3.1. Limestone calcined clay cement (LC^3)

LC^3 cement is a blend of clinker, low-grade limestone, calcined clay, and gypsum. Figure7 shows the composition of LC^3 cement. In the production of LC^3, clay (kaolinitic clay) is calcined at 700°C - 850°C, in the rotary kilns. This clay is then ground along with clinker and other ingredients in the required ratio (Scrivener, et al., 2018). Since only 50% of clinker is required in the production of LC^3, this results in less CO_2 emissions arising due to the chemical conversion of limestone. Moreover, calcination of kaolinitic clay takes place at a much lower temperature as compared to clinker production, which means that less fuel or low-grade fuel is required. Calcined clays are also comparatively soft as compared to OPC clinkers, thus requiring less energy for grinding purposes. Therefore, LC^3 production leads to

lower CO_2 emissions which are approximately 30% lower than the OPC. (Maity, et al., n.d.).

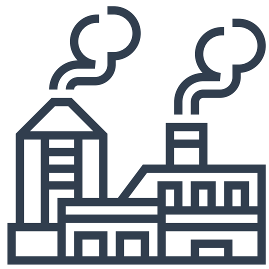
The raw materials like, calcined clay and low-grade limestone which are required for the production of LC^3 are easily available in India (Scrivener, et al., 2018). In India, as of 2015, clay and limestone reserves were 2,941 million tons and 16,336 million tons respectively (IBM, 2016). The use of LC^3, which requires low-grade limestone, reduces the need for the import of high-grade limestone required for the production of OPC. India imported 17.8 million tons of high-grade limestone (having lime content between 44%-52% by mass) in 2015-2016 (IBM, 2017) for the production of OPC.

FIGURE 7: Composition of LC^3 (*Maity, et al.*)



Moreover, the production of LC^3 cement does not require any additional sophisticated equipment. The equipment already available in the cement plants such as old rotary kilns used in wet processing or the kilns already used for calcination can be used for the calcination of clays. Various other techniques like flash calcination, fluidized bed technology, or static calcination can also be used (Scrivener, et al., 2018). In Cuba, the old kilns which were earlier used in wet processing, are now used for the calcination of clays (Scrivener, et al., 2018). Calciners can also be installed at the clay mines itself, which will save around 15% of the material during transportation as the moisture content in the clay will be removed at the site itself, which allows an equivalent amount of clay to be transported, but the availability of infrastructure like, power and equipment available at the mines can pose hurdles.

In India, the research & development on LC^3 is being carried out by multiple organizations including EPFL (École Polytechnique Fédérale de Lausanne), Switzerland; Society for Technology and Action for Rural Advancement (TARA), India (an incubation engine of Development Alternatives); Centro de Investigación y Desarrollo de Estructuras y Materiales (CIDEM) Cuba; and research institutions i.e. IIT Delhi and IIT Madras with Swiss Development Corporation providing the financial support. Feasibility studies conducted in Cuba on LC^3 indicate that it will give a better return on capital investment when compared to OPC (Scrivener, et al., 2018).



Since only

50%

of clinker is required in the production of LC^3, this results in less CO_2 emissions

The pilot projects in India and Cuba shows that the concrete produced by using LC^3 has similar physical and mechanical properties as OPC concrete (Scrivener, et al., 2018). Based on the discussion with industry experts, the Indian cement manufacturers will be able to produce and supply LC^3 for commercial use in the next 2~3 years. From the discussion with stakeholders, it is found that GIS mapping of various kaolinitic clay locations, lime-stone reserves, and thermal power plants have been done to assess the feasible location for LC^3 manufacturing in Rajasthan and Gujrat (Development Alternatives). The calcined clay is available in abundance in the country, some of the states where clay reserves are available are – Rajasthan, Kerala, West Bengal, etc. However, the feasibility of transporting the clay to cement plants needs to be established.

Another area that needs to be strengthened for making the LC^3 cement as a commercial product is to gain the confidence of consumers by developing knowledge products on the benefits of LC^3. There is a need to develop a business case for developers, contractors, and consumers by the assessing techno-economic benefits of LC^3 over traditional cement. There is also a need to explore economic reforms, tax incentives, and market mechanisms for the commercialization of the LC^3. Moreover, it is necessary that government agencies explore possibilities of including LC^3 as part of its public procurement policy.

3.2. Geopolymer Cement and Concrete

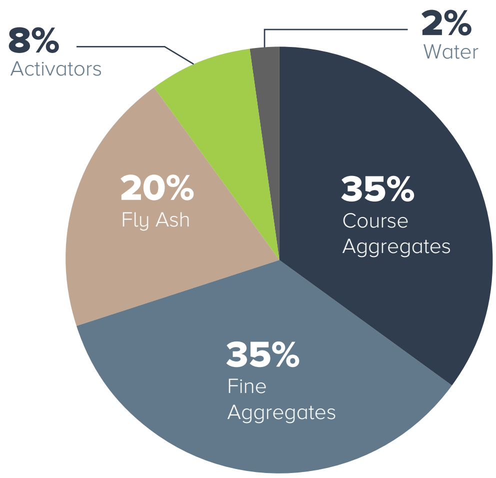
Geopolymers were first introduced by Dr. Joseph Davidovits in the late 1970s. They are produced by the activation of pozzolanic materials (rich in silica and alumina) with alkaline solutions like sodium hydroxide and sodium silicate etc. at required temperatures. Pozzolanic materials when reacted with alkaline solutions form a three-dimensional alumino-silicate complex, which when cured at required elevated temperatures forms a solid structure, which exhibits properties like ordinary Portland cement and can be used as a building material.

For the production of geopolymer concrete (GC), any of the industrial-by products like fly ash, Ground Granulated blast furnace slag (GGBFS), LD slag, silica fumes, kaolinitic clay, red-mud, rice husk ash, pond ash, etc. can be used. Out of these materials, fly ash (a by-product from coal-burning in thermal power stations) and GGBFS (a waste product from the iron and steel industry) are the two most prominent options for the production of geopolymer concrete due to their easy availability. Geopolymer concrete is made by using fly ash or blast furnace slag and has a CO_2 reduction potential of over 80% compared to OPC (Hassan, et al., 2019). A typical composition of geopolymer concrete using fly ash is given in Figure 8. This composition may vary for a different industrial by-product other than fly ash.

India has a good production capacity for the activators like sodium hydroxide (annual production 35.39 Lakh MT in 2018-2019), also sodium silicate is produced by various manufactures in India like Kiran Global Chem Limited, Vizag chemicals, Tata Chemicals, etc. The optimal locations for the production of geopolymer concrete will depend upon various factors like logistics cost for activators and industrials by-products, availability of by-products, quality of raw materials available etc.

In India, there are few manufacturers who have started producing Geopolymer cement commercially, but at a very small scale. With the level of work going on to develop geopolymer cement, it is expected to be available in the next 5-6 years at a commercial scale. Various pioneering organizations such as the National Council for Cement and Building Materials (NCCBM), Central Building Research Institute (CBRI) Roorkee, CSIR- National Metallurgical Laboratory, various IITs and other academic institutions are working on the development of geopolymer concrete.

FIGURE 8: **Typical composition of Geopolymer Concrete (*Tempest, et al., 2015*)**



Several pilot studies have also been conducted to assess the suitability of Geopolymer concrete for construction and infrastructure projects. One such project is where, NTPC and CBRI-Roorkee have developed a high strength fly ash based Geopolymer concrete to construct a road in Dadri Plant of NTPC (500m in length) (NTPC, 2017). Similar work was

also done by CSIR-NML to produce 20 tons of geopolymer concrete for road construction using fly ash from TATA power plant. Furthermore, NTPC has issued a tender in 2019 for the construction of geopolymer roads in NTPC stations, for which the fly ash will be provided at zero cost (NTPC, 2019). This material is also being used globally in the construction of buildings. In Australia, the pavement of Brisbane West Wellcamp Airport in Queensland is constructed using approximately 40,000 m^3 of geopolymer concrete (Glasby, et al., 2015), and a “Global change institute” at the University of Queensland was also made with GC in 2014.

There are some challenges in the production of geopolymer cement/concrete, like consistency in the constituent ingredients of fly ash (silicon and aluminum content) and fineness of fly ash and GGBFS. This poses a challenge in maintaining the quality of geopolymer concrete. Another limitation is the requirement of skilled labor to handle highly alkaline activator solutions, workability, and appropriate proportions of fly ash or slag etc. Therefore, it finds more applications in the pre-cast industry than in-situ. The geopolymer requires elevated temperature for curing, which make it unsuitable for in situ applications, but using additives (like calcium cations) in the concrete mixture would make it suitable for ambient curing.

Currently, there is no BIS standard for the geopolymer concrete. However, based on the discussions with industry experts, BIS has initiated this process and has been reaching out to the manufacturers and also to academic institutions for the standard development work. There is also a need to evaluate the techno-economic feasibility of geopolymer cement which will depend on various factors like availability of industrial by-products with adequate fineness, transportation cost, cost of alkaline activators, and the demand for geopolymer concrete in the Indian market etc.

3.3. Composite Cement

Composite cement is produced by the blend of Portland clinker, fly ash, and slag in the appropriate proportion (CII, 2016). The Portland clinker is finely ground with fly ash and slag along with the required amount of gypsum in the mixture. Due to reduced clinker demand, the CO_2 reduction potential of composite cement is 56%, when compared to OPC. This cement finds its use in various applications like Precast concrete (pipe and block), Building construction, and civil engineering works, dams and retaining walls, etc.

Various trials have been conducted in India, by National Council for Cement and Building Materials (NCB), for the different combinations of ingredient materials, and based on the results, the Bureau of Indian Standards (BIS) has released a standard for composite cement. As per IS 16415:2015, the permitted material proportion for composite cements is given in Table 2.

TABLE 2: Composition of composite cement

Material	Proportion (percentage by weight)
Portland Clinker	35-65
Fly ash	15-35
Granulated Slag	20-50

The production of this cement is dependent on the availability of fly ash and granulated slag near the cement production plant. In India, despite the availability of standards for composite cement, only few manufacturers are producing this cement. It is yet to pick up momentum in the country due to issues like availability of both type of raw materials at the same location, the variable chemical composition of slag and fly ash, availability of equipment required for the processing blast furnace slag, availability of separate silos for storing slag, fly ash and clinker separately (Hegde, 2020).

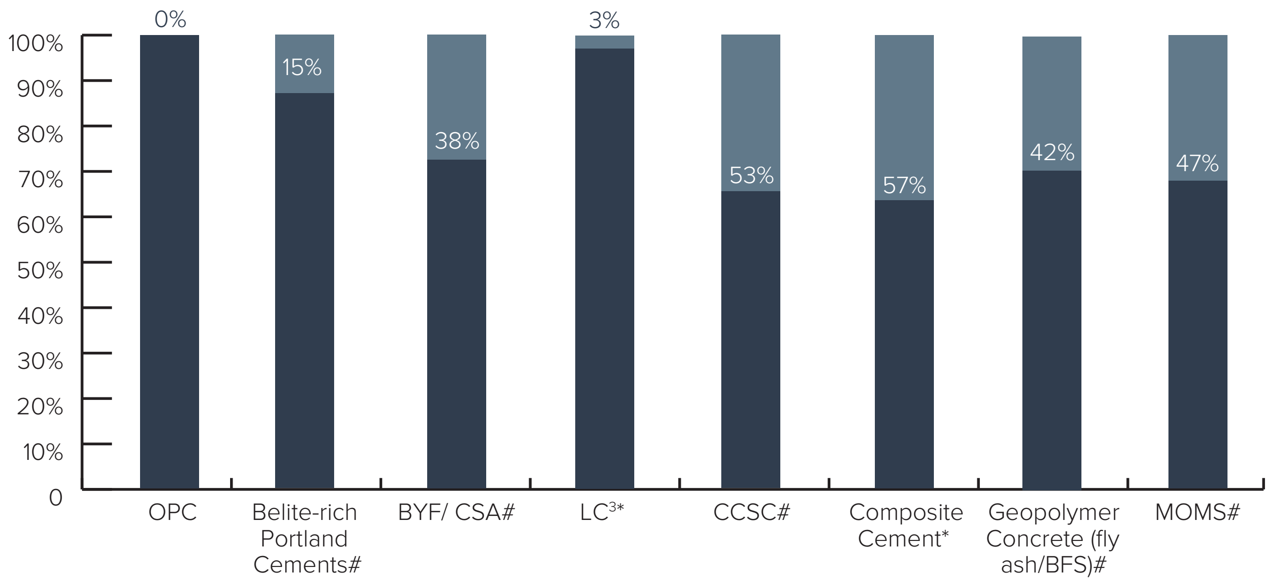
3.4. Other low carbon cements

Apart from the above-mentioned alternatives, there are few more options which are being explored across the globe. These include, cements containing belite like Belite-rich Portland cement (BRPC) and calcium sulfoaluminate (CSA) / Belite-Ye’elimite-Ferrite (BYF) cements having CO_2 reduction potential of 10% and 20% respectively (Scrivener, et al., 2017) (Naqi & Jang, 2019). Similarly, there are few Novel cements like Carbonatable calcium silicate cements (CCSC) and Magnesium Oxide-based cements derived from magnesium silicates (MOMS). CCSC has a CO_2 reduction potential of 30% (Sahu & Meyer, 2020), whereas MOMS are carbon negative cements and have a CO_2 reduction potential of more than 100% (The American Ceramic Society, 2011). CCSC is being developed by a US-based company named Solidia Technologies, Inc. for which they have a received a patent and this product is in the advance stages of development. They have partnered with LafargeHolcim in US to commercialize their product in 2019 (LafargeHolcim, 2019).

3.5. Energy and Emission reduction potential of low carbon cements

The energy and emission reduction potential of various low carbon cements as compared to OPC is provided in Figure 9 and Figure 10 below respectively.

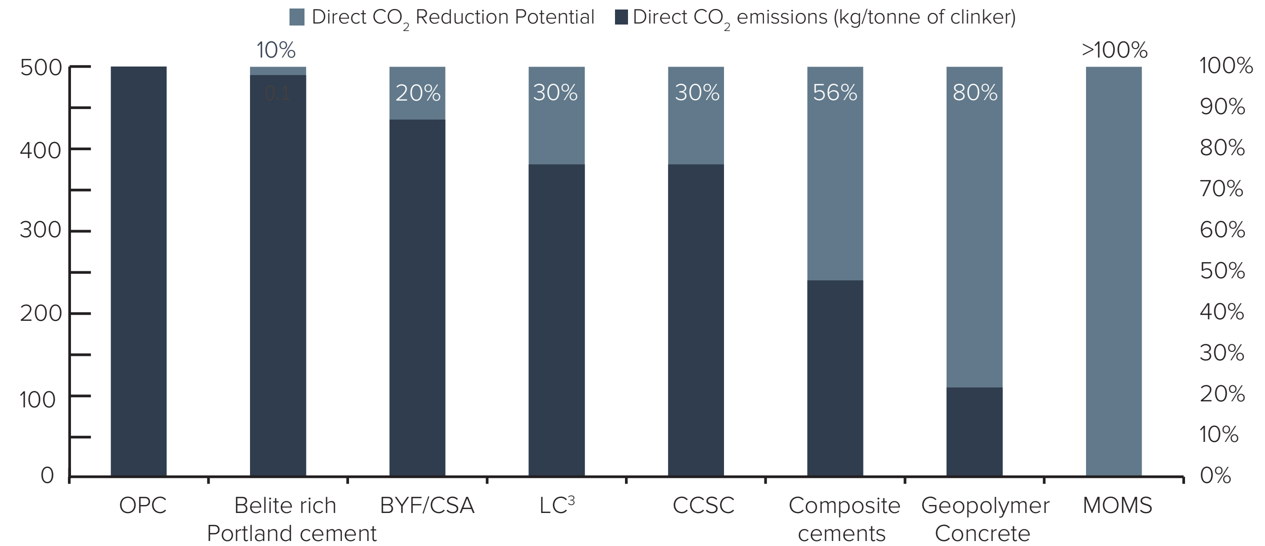
FIGURE 9: Energy reduction potential of various low carbon cements w.r.t OPC



*Note: *Based on gate to gate concept (SEC for OPC 3.38 GJ/ton) (CMA); #Based on thermodynamic principles (Gartner & Sui, 2017); SEC for OPC clinker based on thermodynamic principles is 1.63 GJ/ton (Gartner & Sui, 2017)*

Figure 9, depicts the specific energy reduction potential of various low carbon cements in comparison with OPC. Reduction in specific energy consumption only impacts the emissions related to energy use during the cement production process. The composite cement which is commercially available has the highest energy reduction potential of 57% w.r.t OPC. The other promising options like LC^3, and Geopolymer has an energy reduction potential of 3% and 42% respectively compared with OPC.

FIGURE 10: CO_2 reduction potential of various low carbon cements



From Figure 10, it can be observed that the CO_2 reduction potential of various low carbon alternate cements ranges from 10% to 100% and even more as compared to OPC. The promising alternatives like LC^3 and geopolymer concrete which are in the advanced stages of development in India have an emission reduction potential of 30% and 80% respectively.

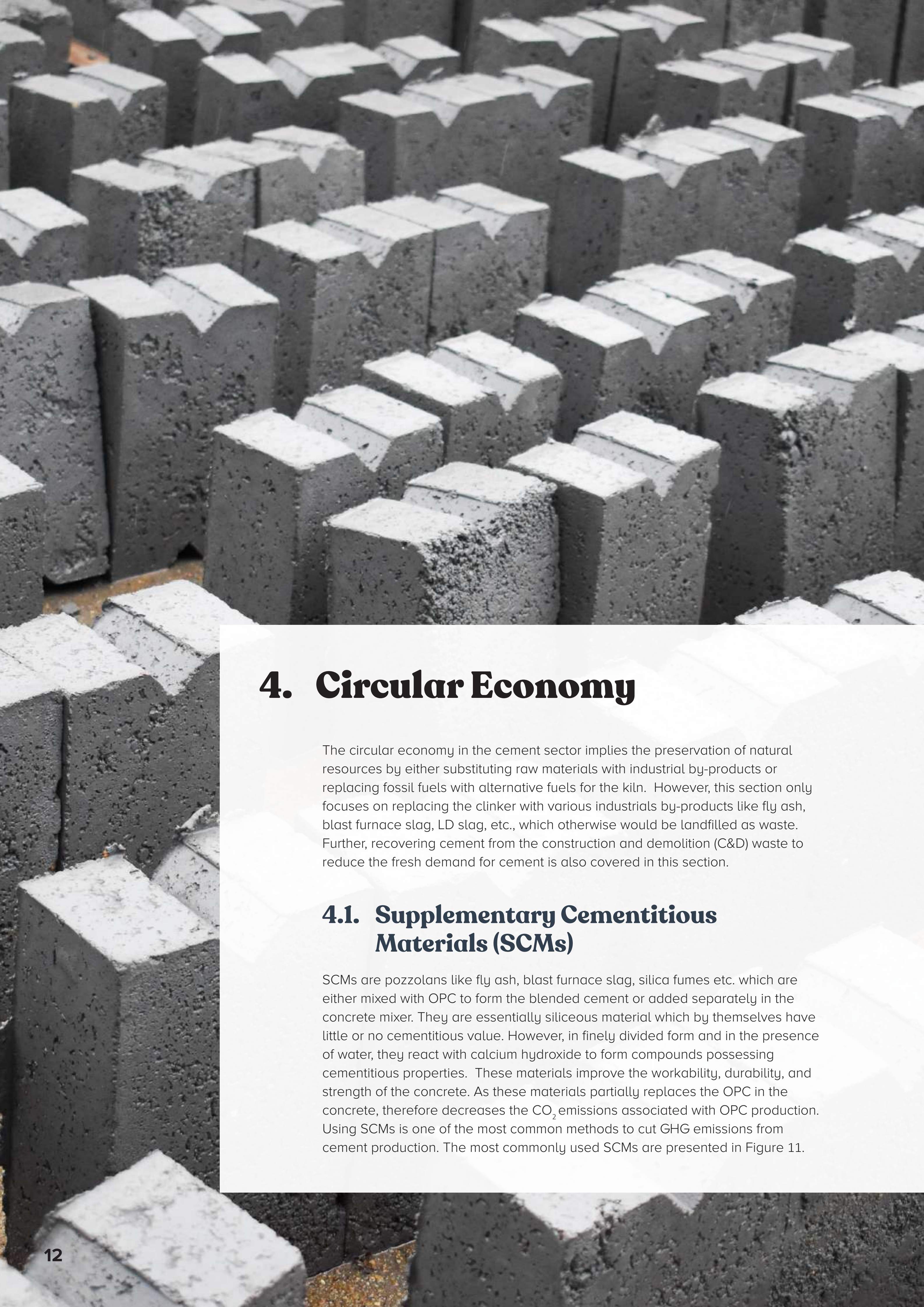
3.6. Comparison of various low carbon cements

The various low carbon cements as discussed in previous sections have been compared on different parameters as shown in Table 3. This highlights the status of development of each alternative cement in terms of availability of standards, pilot demonstrations, and availability of raw materials in the country.

TABLE 3: Comparative assessment of various Low carbon alternates

Alternative cement options	Raw Material availability in India	Status of BIS Standard	Pilot Projects Status
LC^3	Yes	Draft standard submitted to BIS	Country: India; Year: 2014,2018; Application: Residential and office building.
Composite Cement	Yes	Available; IS 16415: 2015	Not required; already being used for commercial applications
Geopolymer Concrete (fly ash/GGBFS)	Yes	In Progress	Country: Australia; Year: 2014; Category: Office building Country: India; Year: 2017; Application: NTPC Road, Pothole Repair in Roads in Chennai, Sewage treatment plant (20,000 m3)
Belite-rich Portland Cements	Yes	None	None
BYF/ CSA - Belite cements	No; scarcity of aluminum-rich materials	None	None
MOMS	No; scarcity of natural ore for producing magnesium silicates	None	None
Carbonatable calcium silicate cements	Yes	None	Country: USA; Year: 2015 Application: Concrete Paver blocks (by Solidia Cement)

The table above highlights that LC^3 and Geopolymer have been successful in demonstrating the performance through pilot projects and therefore are now ready for commercialization as compared to other alternate materials. There is a need for accelerating the development of BIS standards for market deployment, creating awareness among consumers, and boosting the demand for these low carbon cements through policy support and market mechanisms.



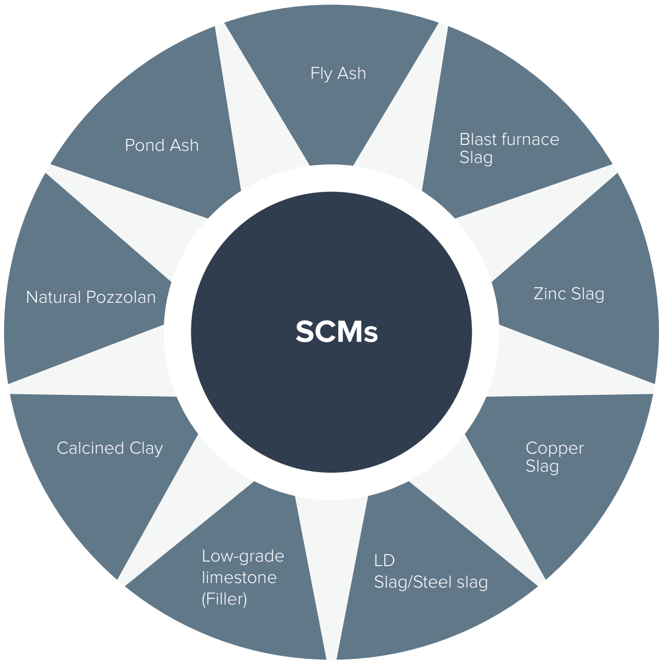
4. Circular Economy

The circular economy in the cement sector implies the preservation of natural resources by either substituting raw materials with industrial by-products or replacing fossil fuels with alternative fuels for the kiln. However, this section only focuses on replacing the clinker with various industrials by-products like fly ash, blast furnace slag, LD slag, etc., which otherwise would be landfilled as waste. Further, recovering cement from the construction and demolition (C&D) waste to reduce the fresh demand for cement is also covered in this section.

4.1. Supplementary Cementitious Materials (SCMs)

SCMs are pozzolans like fly ash, blast furnace slag, silica fumes etc. which are either mixed with OPC to form the blended cement or added separately in the concrete mixer. They are essentially siliceous material which by themselves have little or no cementitious value. However, in finely divided form and in the presence of water, they react with calcium hydroxide to form compounds possessing cementitious properties. These materials improve the workability, durability, and strength of the concrete. As these materials partially replaces the OPC in the concrete, therefore decreases the CO_2 emissions associated with OPC production. Using SCMs is one of the most common methods to cut GHG emissions from cement production. The most commonly used SCMs are presented in Figure 11.

FIGURE 11: Various SCMs used in the cement industry

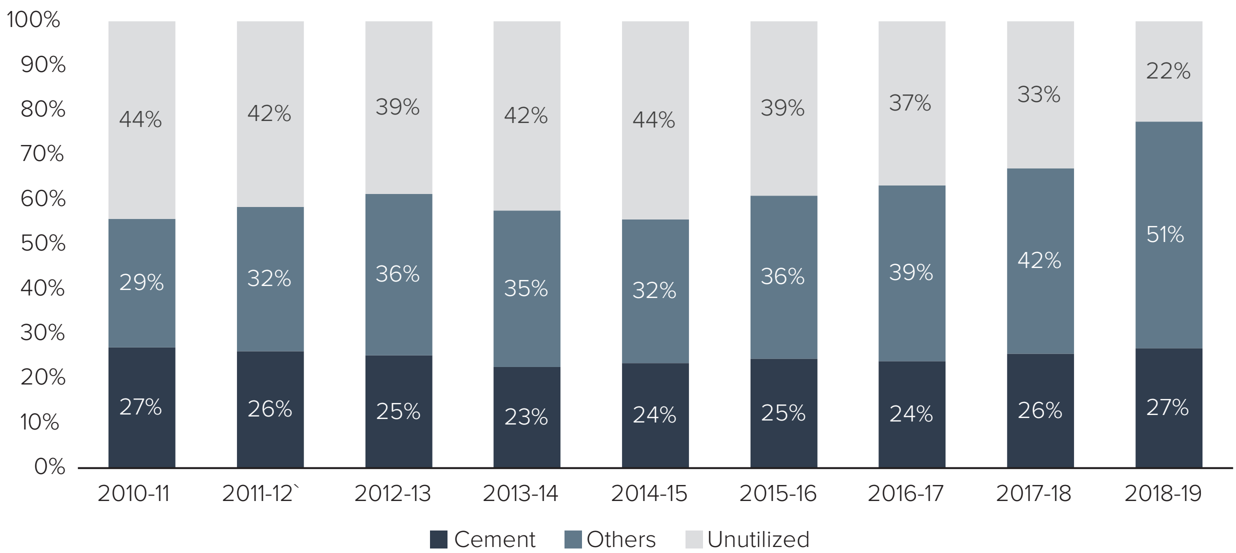


4.1.1. Fly ash

Fly ash is a by-product of burning coal in power generating plants. It comes out with the exhaust gases from the burning zone in the boiler and is collected by electrostatic precipitators or bag filters. Fly ash is pozzolanic material which when mixed with Portland clinker and water forms calcium-silicate-hydrates and calcium aluminum hydrates. The inclusion of fly ash is beneficial in terms of improving the long-term strength and reducing the permeability. The fly ash is inter-grinded with Portland cement and is used for the production of Portland Pozzolana Cement (PPC) and composite cement. The total availability of fly ash and its utilization in cement production over the years from 2010-19 is shown in Figure 12. Out of the total fly ash available in the country in 2018-19, only 27% was utilized in the production of cement, while 51% fly ash was used in other applications, and 22% remains unutilized.

The Indian standard IS 1489-1: 2015 (Portland Pozzolana Cement Fly ash based), allows up to 35% clinker substitution with the fly ash. On the other hand, the European standard permits 55% substitution with fly ash in CEM IV/B (a type of cement). In India, NCCBM is conducting research to further increase the fly ash percentage in the blended cements (NCCBM, 2020). The PPC in India is produced by almost all the major cement manufacturers and it has the highest share in the country's cement mix.

FIGURE 12: Fly ash production and utilization in India



The Government has taken several actions for fly ash management and its optimum utilization. In this regard, MoEFCC has come up with the notification on 100% fly ash utilization by Thermal Power Plants by providing fly ash to brick manufacturers, cement units at 1 Rs. Per tonne and bear full transportation cost. Moreover, NPTC has developed an infrastructure at Rihand thermal power station (U.P.) to transport fly ash at a cheaper cost to the nearby cement plants.

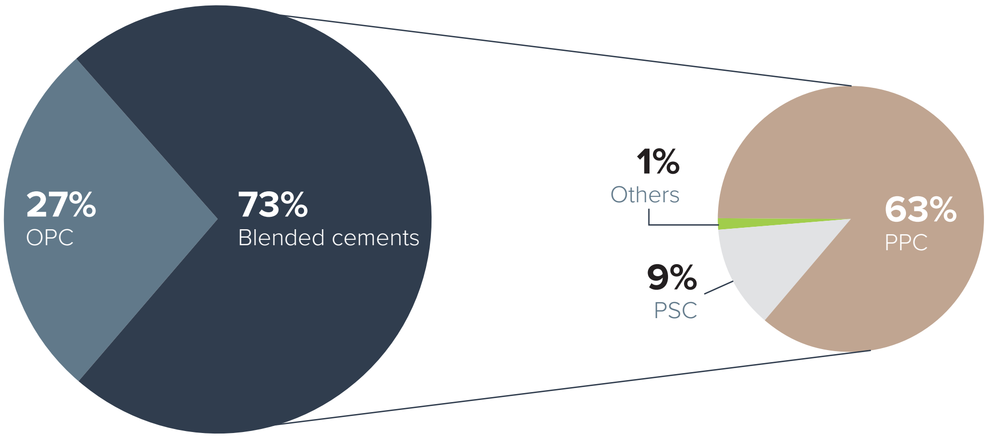
4.1.2. Blast furnace slag

Blast furnace slag is a non-metallic industrial by-product generated during the manufacturing of pig iron from iron ore in the blast furnace. The slag comes out in the liquid form which is then cooled to form granules and grounded to suitable fineness to produce a powder to be mixed with the ordinary Portland cement. India currently produces 27 million tons of blast furnace slag. The production of blast furnace slag is expected to increase in the coming years and will reach around 45-50 million tons by 2030 (NITI Aayog, 2018).

This SCM is already in use in India for the production of Pozzolana Slag Cement (PSC) and composite cement. According to Indian standards IS 455: 2015 (Portland Slag Cement), the amount of slag allowed in PSC is up to 65% by weight (IBM, 2017). However, as per the European standards, in CEM III (a type of cement), up to 95% of the slag substitution is allowed. Increasing the percentage of slag would help to reduce the clinker content of cement and hence the emissions associated. Major cement manufacturers like JSW cement, Dalmia cement, ACC, JK cement, etc. are producing Pozzolana slag cement and Composite cement in India. One of the potential barriers to the production of PSC is the availability of slag near the cement production plants in India.

The percentage share of different types of cements in the national cement mix in 2017 is shown below in Figure 13.

FIGURE 13: Share of different types of cements in the country's cement mix



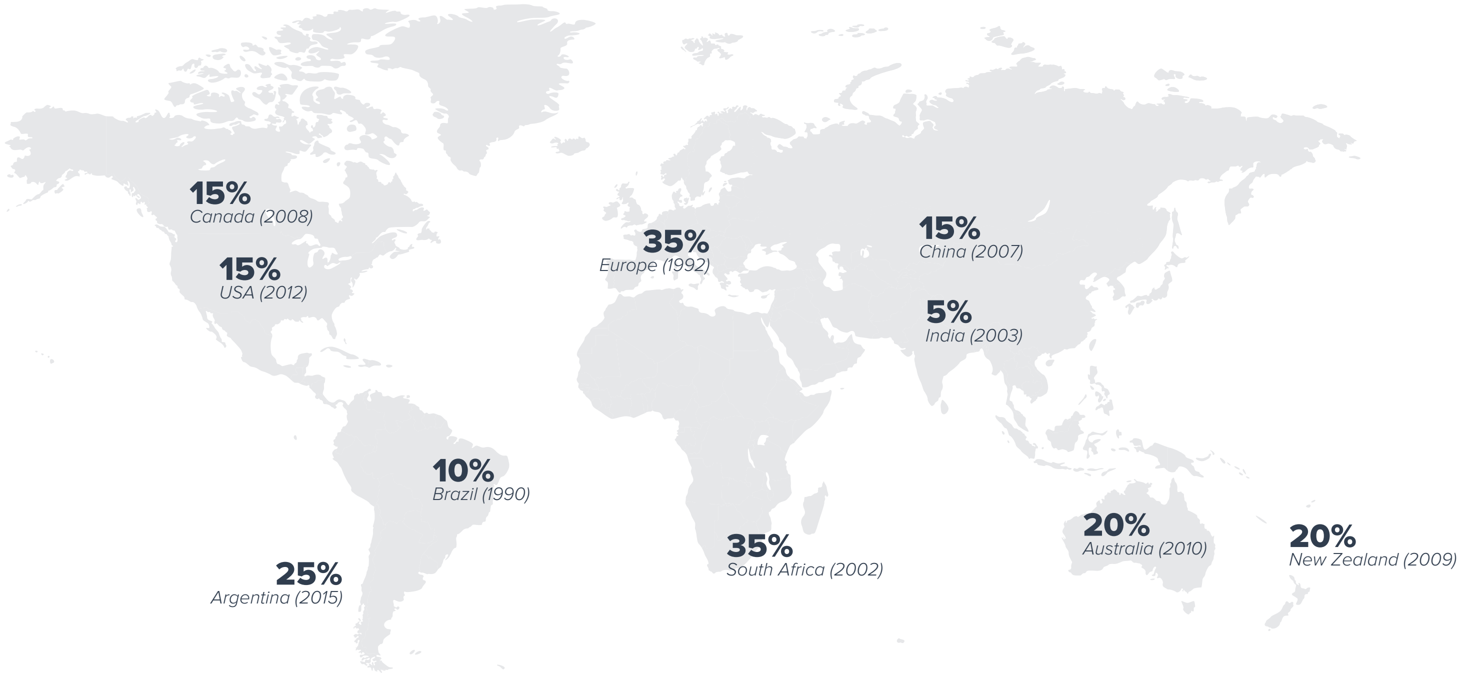
The share of PPC, PSC, and OPC is 63%, 9%, and 27% respectively in the total cement produced in the country. Other cements that are produced in India include composite cements, rapid hardening cement, low heat cement, etc.

4.1.3. Low-grade limestone as a filler

Fillers are fine particles which are inert in nature and are mixed to replace clinker in cement. They are produced by grinding and are used as a partial replacement for clinker and other SCMs. Low-grade limestone is one of the most prominent fillers which is used in the cement industry as SCM. Moreover, they do not require calcining, which makes them a prominent option from an economic and environmental perspective as only grinding is required for production. Low-grade limestone is mixed with clinker to produce Portland limestone cement. In the current scenario, 5%-35% limestone substitution is permitted under various standards across various countries. In India, 5% of limestone is allowed filler for performance improvement in OPC according to IS 269: 2013 (BIS, 2013). Standard adoption by various countries and permissible limestone substitution is presented in Figure 14.

Recent research shows that it is possible to achieve a replacement of 70% clinker by low-grade limestone (filler) without impacting the strength. Fillers can also be used with all new binders, including geopolymers, carbonation-hardening cements, LC^3, and cement made with clinkers such as BYF and CSA (John, et al., 2017). In the Indian context, low-grade limestone is abundantly available for utilization as filler in Portland limestone cement. This cement is produced in Europe and has specific standards developed for the production of Portland limestone cement whereas, in India, no such standards are available.

FIGURE 14: Maximum limestone filler limit and the year of Standard adoption by different countries (John, et al., 2017)



4.1.4. Calcined Clay

Clay containing kaolinite, when calcined at 700°C-850°C, produces reactive materials that can be used as a replacement for clinker and other prominently use SCMs like fly ash and slag. It possesses higher reactivity than fly ash and slag, due to the presence of high aluminum content. The quality of clay required to be used as SCM is not as high as required by the ceramic and refractory. Therefore, clay having a kaolinite content of only 40% can be used as SCM in cement production (Scrivener, et al., 2018).

Further the availability of fly ash and BF slag will be limited in the future. The electricity generation will transition from coal-based generation to renewable energy or cleaner sources, which will reduce the availability of fly ash. Moreover, due to the introduction of the National steel scrap policy, the production of blast furnace slag is also expected to reduce with time as the policy promotes the use of scrap-based steel production which will reduce the operation of blast furnace so does the slag production. Under these circumstances, the calcined clay can gradually replace these SCMs in clinker replacement, as clay is available in abundance in India and only high-quality clay is used by the ceramic industry resulting in a substantial amount of clay being stockpiled as waste. In India, there are no standards available for the use of clay in cement production, although research on cements like LC^3 is going on in India which enables the use of clay in cement production.

4.1.5. Pond ash

The Fly ash which remains unutilized at the TPPs is dumped into the landfills Called ash ponds. Over the year, this leftover unutilized ash has accumulated and now has become an environmental hazard for the country. Since ash is pozzolanic in nature, it can be utilized in the production of PPC, composite cement, or geopolymer cement.

From Figure 12, it can be realized that, in the past decade, around 1/3 of the fly ash produced remains unutilized and gets deposited into the ash ponds and depletes the surrounding environment. Utilization of Pond ash can prove to be very helpful to the country's target of waste utilization and implementing circular economy principles. Not much work is happing on the utilization of pond ash in cement production. Only a few manufactures like JK cement are utilizing pond ash at their facilities (JK Cement Limited, 2017).

Apart from the above-mentioned materials, there are several other SCMs like, LD slag (a by-product of steel production), Natural Pozzolan, Silica fumes, Copper slag, Zing slag, by-products from the aluminum industry, bauxite residue, etc., on which research is taking place to find their use in the cement industry.

4.2. Utilization of Construction and Demolition (C&D) waste

C&D waste is generated from, construction, renovation, and demolition activities and it consist of wood, steel, concrete, etc. Increasing urbanization and construction boom is resulting in increased C&D waste in the country and it is expected

to rise in the near future. In India, various organizations like CPWD, BMTPC, MoHUA, etc have laid down rules for the management of C&D waste in the country, but the implementation of these rules can be stepped up. The C&D waste generated is usually dumped in an unauthorized manner along the roadside, in the open public areas, and the municipal bins (by individual households).

Moreover, in India, there is no reliable estimate of the annual C&D generation (NITI Aayog, MoHUA, 2018). BMTPC has estimated annual C&D waste generation in the country as 100 million tons (BMTPC, 2018).

In the current C&D waste management practices, the recoverables like metal rods, pipes, fixtures, wooden frames, etc are salvaged in the market and leaves behind rubble which consists of concrete, stones, sand, etc. This rubble can be used in various applications like landscaping, earthworks, aggregates in concrete, etc as advised in “C&D waste management rules, 2016” (MoEFCC, 2016). The reuse of the waste is the prime objective of these rules and guidelines. However, to reduce the demand of cement in the construction sector, there is a need to recycle the rubble waste and reutilize it in the newly constructed buildings and infrastructure. There are few technologies which aim to recover cement from the C&D rubble are presented next

SmartCrusher

In Netherlands, research is going on to develop technologies to reuse concrete and make it a part of the circular economy. One such technology is “SmartCrusher” (SC). This technology was developed by Koos Schenk and was patented under his name in 2011. SC was developed to recover sand, gravel, hydrated and unhydrated cement (accounting for 30-40% of the initial cement used) from concrete. It works on the principle that different components of the concrete have different crushing strength which helps to separate them. This technology has been tested in the laboratory and a pilot demonstration has been made in Wilp, Netherlands. The pilot results show that SC uses 10% of the energy as used by traditional crusher (TU Delft, 2015). Sand and gravel recovered by this technology is better in quality and can save up to 25% of the cement in the new constructions.

Although SC shows a remarkable opportunity in terms of material savings and demand reduction, a country level assessment is required to be done to find the suitability of this technology in the Indian conditions. Moreover, this is a patented technology, economic feasibility analysis is also required to deploy such technologies.

5. Design Optimization Techniques

The amount of cement or concrete used in the construction of a building or a structure is largely dependent on the design of a building. Sustainable design practices focus on reducing the use of depleting resources and prevent environmental degradation. The most prominent techniques which can be used in the construction sector to reduce the cement demand are:

1. Voided concrete slab technology/ Bubble Deck Technology
2. Confined Masonry
3. Cross-Laminated Timber
4. Design for Deconstruction
5. 3-D Printing

5.1. Voided Concrete Slab Technology/ Bubble Deck Technology

In a building, slab accounts for most of the weight of a building and carries most of the concrete volume used in a building. This weight puts a strain on the slab and exerts a lot of burden on the foundation and framework of the building. One of the ways to reduce the concrete consumption in the slab is by creating engineered voids in the slab. These voids are filled with spherical or oval or cubical hollow structures made of recycled plastics and are placed in such a way, that they do not impact the strength of the structure. Since beams and columns are the load-bearing components of the building, so, these voided structures are generally placed away from them.

FIGURE 15: Benefits of using Voided slab technology/ Bubble Deck technology

Weight Reduction

- Longer span length can be achieved
- Lighter foundation due to reduced slab weight
- Thinner columns needed for carring the building weight

Material savings

- Less concrete required
- Less Reinforcement required

Waste reduction

- Utilizes recycled plastic for viod formers
- Less construction material required, lesser generation of C&D waste

Environmental benefits

- Lower cement requirement will have direct impact on the associated CO_2 emissions.

Presently, technology providers in India and around the globe are using voided slabs technology along with post-tensioning. This technique is economically viable and suitable for building and structures, where span length is more than 7 meters and the thickness of the slab is more than 200 mm. It is claimed by the technology providers that with the use of this technology, material savings of 25%-30% and 10% on concrete and reinforcement respectively can be achieved. Various benefits of using this technology are listed in Figure 15.

Various projects around the globe have been completed by using this technology. A few of the examples from the site during construction are given in Figure 16 and Figure 17.

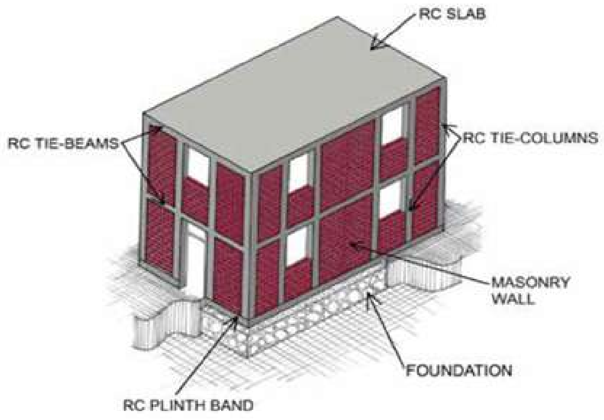
FIGURE 16**: Shaktidham Temple, Aurangabad, Indi**a (Post Tention Services India Ltd.**)**

FIGURE 17**: The Pérez Art Museum, Miam**i (CobiaxUSA**)**

5.2. Confined Masonry

Confined masonry is a construction technique in which masonry walls carry the load of the building. These masonry walls are enclosed by horizontal and vertical Reinforced Concrete (RC) elements like tie-beams and tie- columns. The RC elements provide confinement and strength to the masonry walls and protect them against the seismic loads. The key component of the confined masonry building is given in Figure 18.

FIGURE 18: Component of confined masonry building



Confined masonry buildings look almost similar to the conventional RC frame buildings, but the major difference between the two is the sequence of construction. In confined masonry, the walls of the building are constructed first before the RC elements, whereas, in RC frame buildings, the frame is constructed first, due to which the load of the building in RC frame buildings is carried by RC elements but not by the walls. In confined masonry, the load is carried by the walls and RC elements are used to confine the walls, due to which, smaller RC elements (as compared to RC frame buildings) is required in confined masonry structures which reduces the requirement of concrete and steel usage is the construction (Borah, et al., 2019).

This technology was used in IIT Gandhinagar for the construction of hostel buildings and faculty and staff houses. This construction was started in 2013 and was completed in 2016. The construction included 30 faculty houses (Ground+2) and 6 student hostels (Ground+3) (IITGN, 2015). For comparing the material consumption an academic building is taken as a reference which was made of RC frame with masonry infill. The details of the materials used for the construction are given in Table 4

TABLE 4: Material consumption in different buildings at IIT Gandhinagar project (IITGN, 2015)

Building Type	Construction technique	Build-up area (m2)	Concrete used (m3)	Steel used (tons)
Academic buildings	RC frame with Masonry infill	45,200	39,000	5,210
Hostels	Confined Masonry	35,943	13,049	1,602
Faculty and staff housing	Confined Masonry	49,270	15,266	1,968

From Table 4, it can be observed that in the case of confined masonry, less amount of concrete is utilized (0.30 m^3/ unit area for faculty and staff housing; 0.36 m^3/unit area for hostels), whereas, in academic building 0.86 m^3/unit area of concrete was used. Similar is the case in steel consumption which is high in the case of the RC frame with masonry infill. Since this technology seems promising for residential buildings, which means it can be used in low-cost housing projects under PMAY. There is a need for awareness creation among builders and construction agencies on the benefits of using this technology in terms of cost and material savings.

Also, a guide book is prepared by Competence Center for Reconstruction, SDC/Humanitarian Aid Unit, and Earthquake Engineering Research Institute (EERI) for the use of this technology in low-rise buildings, where the instructions on various aspects are given for the builders and workers (CCR, et al., 2015). For example, buildings should be made in simple shapes (preferably rectangular) and the vertical continuity of the walls should be maintained.

5.3. Cross-Laminated Timber

With the widespread use of concrete and steel, the use of wood in construction has decreased significantly. But with the development of cross-laminated timber in Europe in the early 1990s, the use of timber in the multi-story building has started picking up. Cross-laminated timber (CLT) is a prefabricated and engineered wood panel.

It is made by drying the timber boards (lamellas) and placing them over each other in such a way that the grains of the timber are placed perpendicular to each other, as shown in Figure 19. Lamellas are glued to each other using adhesives and then pressed hydraulically against each other to achieve strength.

Now with the advancement in the development of CLT, it can be used in almost any type of building be it commercial, residential, industrial, etc (Beyond Zero Emissions, 2017). CLT can be used in the construction of walls, floors, roofs, etc. The use of timber in the construction sector will help to reduce the usage of concrete by a significant amount. The amount of concrete saved will vary from project to project. There few examples from around the globe, given in Table 5, where CLT is used successfully to reduce the consumption of concrete.

TABLE 5: **Examples of the use of timber in building construction to avoid concrete usage**

Building	Description	Concrete avoided m^3
Forte, Melbourne, Australia; 2012	10-story apartment building	1000
Library at the Dock, Melbourne; 2014	3-story Library	574
T3, Minneapolis, U. S; 2016	7-story office	3,600
Treet Apartment, Norway; 2015	14- story apartment block	935
Brock Commons, Vancouver, Canada	18-story student residence	2,650

FIGURE 18: **Cross laminated timber block (*Souza, 2018*)**

Apart from material saving, there are other benefits too of the use of timber in buildings like reduction in construction time, flexibility in design, better thermal performance etc.

In the Indian context, the use of timber in construction activities was banned from 1993, but on the advice of the Union Environment Ministry the prime construction agency of the country, CPWD has lifted this ban from 1st July 2020 (CPWD, 2020). This will encourage the use of timber in India for the construction of housing and other related activities. The use of timber will not only reduce the use of carbon-intensive materials like cement and steel but will also help to realize the NDC target of creating 2.5-3 billion MT of CO_2 equivalent by increasing the green cover. As the increased demand for wood will encourage the farmers to bring the degraded land under tree cover (CPWD, 2020).

For using timber in construction activities in India, there is a need to carry out a feasibility analysis (technical and economical) which will help to determine the preferred geographies (climate zones) where it can be used. It is also required to be evaluated in which elements of the buildings, timber can easily be used in that climate zone. Moreover, there is a need to evaluate the requirement and availability of timber stock in the country, to grow and use it sustainably. The development of a standard methodology is required for calculating the amount of CO_2 mitigated and sequestrated due to the use of timber in various construction activities.

5.4. Other technologies

Design for deconstruction and 3-D printing are some of the other design optimization techniques which are being explored around the globe. Design for Deconstruction (DfD) is a technique in which buildings are constructed in such a way, that they can be disassembled and reused for some other purposes and in new constructions. On the other hand, 3-D printing is a technique in which computer-controlled sequential layering is done to create three-dimensional structures. With the use of this technique, structures can be made in a faster and efficient manner. Also, very minimal material is wasted during the construction as compared to conventional techniques.

6. Existing policy framework

Despite the emission reduction targets specified under the Paris agreement, India needs strong policy interventions that clearly specifies emissions reduction through demand reduction strategies from the cement industry. The demand reduction strategies comprising of alternate low carbon materials and demand optimization require strong policy level support to find their place in the Indian market. The current policies are only focused on energy efficiency and waste utilization measures in the cement sector. Some of these are enlisted in table below.

Policy/ Notification	Highlights
PAT scheme	• Launched in 2012 to improve the energy efficiency of large-scale industries by reducing the specific energy consumption. • It is a multi-cycle scheme. Cycle VI was notified in April 2020. • PAT Cycle 1 has an overwhelming achievement of 8.67 mtoe of energy savings and 31 million tons of CO_2 reduction. Results for PAT cycle II is under review.
Waste Management rules (2016)	• Industrial units using fuel within 100 km of Refused derived fuel (RDF) plant should replace 5% of the fuel with RDF • High calorific value waste should be used in cement plant for co-processing • Co-processing has been indicated as a preferred mechanism over the disposal of hazardous waste. • SPCBs to prepare an annual inventory on waste generated, recycled, recovered, utilized as co-processing and disposed.
Fly ash utilization Policy 2009 and Draft Amendment 2019	• According to notification (MoEFCC in 2009), all the power plants should have achieved 100% utilization of fly ash by 2014. • In the Draft amendment 2019, no new red clay brick kiln should be installed within 300 km from the thermal power plant (TPP), and the existing should be converted to fly ash brick manufacturing unit. • Also, TPPs should provide fly ash for brick manufacturing at Re 1/ ton of fly ash and bear the transportation cost.
Timber Usage Notification	• The use of timber was banned in 1993 and lifted on 1st July 2020. • This will encourage farmers to use the degraded land for tree plantation and will reduce the usage of energy-intensive materials like cement, steel, etc.
C&D waste management	• The waste generator is responsible for the collection and disposal of C&D waste at the designated location. • ULBs to monitor all the activities related to proper management of C&D waste in collaboration with state agencies. • Suggests Indian road congress to use recycled C&D waste in road construction

7. Conclusion and Way forward

The cement industry has a big role to play in the development of the nation in the years to come. On one hand, cement is the most used industrial commodity required for infrastructure development, but on the other hand, it is also responsible for high GHG emissions. Hence, there is a need to create a balance between infrastructure growth and maintaining environmental sustainability through emission reduction strategies deployed in the production and consumption of cement beyond energy efficiency.

As discussed in the report, switching traditional OPC with low carbon alternate materials like LC^3, Geopolymer, Composite cement, and others can significantly reduce the emissions associated with OPC production. Further, the demand optimization strategies like efficiency in material design, efficient use of material during construction, and the circular economy look promising options for emission reduction from the cement industry.

To enable this transition there is a need to perform a comprehensive assessment of various demand reduction interventions through research and consultation with relevant stakeholders, engaging and influencing policymakers, and accelerating the deployment of feasible strategies through market mechanisms and policy interventions for energy and emission reduction.

While moving forward there is a need to initiate urgent actions towards the low carbon transition in the cement sector by investigating alternate low carbon materials and demand optimization interventions. Some of the activities planned as the next step are listed below –

- Conducting detailed feasibility of alternate low carbon cement in terms of availability of raw materials & industrial by-products, import requirements, geographical mapping of raw material resources and cement plants, industry collaborations, technology exchange, cost economics among others.
- Assessment of various material design optimization strategies like an efficient use of materials during design & construction, minimizing the wastage during construction, designing buildings for longevity, implementing best practices of circular design including recycle, reuse among others. Further, global best practices on demand optimization and its feasibility in the Indian context will be assessed

- Estimating the potential of various alternate low carbon cements and demand optimization strategies (as above), under the different scenarios, in reducing the emissions and energy consumption from the Indian cement industry.
- Identifying various barriers & challenges in the deployment of low carbon strategies. The need for institutional support, policy, and regulations, market mechanisms, economic incentives, standard developments, design guidelines, training, and capacity building will be carried out to address the identified issues.
- Creating awareness among the developers, architects, contractors, and the user community towards the alternate low carbon cements, circular economy principles, and design optimization strategies for enhanced acceptability
- Developing a roadmap for the low carbon cement sector transition considering the alternate low carbon materials and demand optimization strategies. Identifying the ecosystem for the implementation of the roadmap with respect to research and development, financial need, policy support, market mechanisms, etc. for accelerated deployment.

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