



Cement Sustainability Initiative (CSI), a member-led program of the World Business Council for Sustainable Development (WBCSD)

# Existing and Potential Technologies for Carbon Emissions Reductions in the Indian Cement Industry

A set of technical papers produced for the project 'Low Carbon Technology Roadmap for the Indian Cement Industry'



Public Disclosure Authorized

Public Disclosure Authorized

Authorized

Public Disclosure



An initiative of



In consultation with



Supported by



# **Existing and Potential Technologies for Carbon Emissions Reductions in the Indian Cement Industry**

A set of technical papers produced for the project  
'Low Carbon Technology Roadmap for the  
Indian Cement Industry'



# Contents

<b>Introduction</b> .....	5
<b>Partner summaries</b> .....	6
<b>Overview of the Indian cement industry</b> .....	9
<b>Best Available Technologies (BAT) for a modern cement plant</b> .....	10
<b>Technical papers</b> .....	13
1. Electrical and thermal energy efficiency improvements in kilns and preheaters .....	13
2. Latest generation high efficiency clinker coolers.....	16
3. Energy efficiency in grinding systems.....	18
4. Retrofit uni-flow burner with advanced multi-channel burner .....	21
5. Energy efficiency improvement in process fans.....	23
6. Energy efficiency improvement in auxiliary equipment in the cement manufacturing process.....	26
7. Energy efficiency improvement in Captive Power Plants (CPP).....	28
8. Increased Renewable Energy (RE) use for cement manufacture .....	31
9. Energy efficiency improvement in electrical systems .....	34
10. Utilization of advanced automation systems in cement manufacture .....	36
11. Increasing Thermal Substitution Rate (TSR) in Indian cement plants to 25.3% .....	38
12. Opportunities for exploring development of energy plantation by the cement industry .....	45
13. Reducing clinker factor in fly ash based Portland Pozzolona Cement (PPC).....	48
14. Reducing clinker factor in slag based Portland Slag Cement (PSC) .....	51
15. Reducing clinker factor by using other blending materials .....	54
16. Reducing clinker factor by using low grade limestone.....	56
17. Belite cement from low grade limestone.....	58
18. Alternative de-carbonated raw materials for clinker production.....	60
19. Improving the burnability of raw mix by use of mineralizer .....	62
20. Fluidized Bed Advanced Cement Kiln System (FAKS) .....	65
21. Fuel cell technology .....	67
22. Futuristic comminution technologies .....	69
23. Carbon capture through algal growth and use of biofuels * .....	72
24. Waste heat recovery.....	77
25. Geopolymer cement .....	80
26. Use of nanotechnology in cement production .....	82
27. Developing national standards on composite cements.....	85

Contd...

**Annexures ..... 87**

Annexure I Glossary of terms ..... 87

Annexure II Definition of Reference, Best Available Technology (BAT) and Target plants ..... 88

\*To see further papers on the potential of carbon emissions reductions through carbon capture technologies in the cement industry, see 'Development of State of the Art Techniques in Cement Manufacturing: Trying to Look Ahead', developed by the European Cement Research Academy (ECRA) in 2009.

Authors: Confederation of Indian Industry (CII) lead-authored paper 1 to 12 and paper on Best Available Technologies, and National Council for Cement and Building Material (NCB) lead-authored paper 13 to 27.

# Introduction

This set of technical papers was commissioned by the Cement Sustainability Initiative (CSI) members in India. CSI is a member-led program of the World Business Council for Sustainable Development (WBCSD). The report represents the independent work of the CII – Godrej Green Business Centre (CII – Godrej GBC), a centre of excellence of Confederation of Indian Industry (CII) and the National Council for Cement and Building Materials (NCB). The author of each paper is shown after its title. It aims to identify, describe and evaluate technologies, which may contribute to increased energy efficiencies and reduced greenhouse gas emissions from cement production in India today and in the longer-term. The results have been reviewed by CII, NCB, CSI member companies and stakeholders like the International Energy Agency (IEA).

The roadmap development has been technically supported and part-funded by the International Finance Corporation (IFC).

These papers are based on a set of technical papers titled ‘Development of State of the Art Techniques in Cement Manufacturing: Trying to Look Ahead’, developed by the European Cement Research Academy (ECRA) in 2009. Where no further technological developments have been made since the ECRA papers, the 2009 information is not repeated here.

All papers follow the same format, outlining the current status of the technology, the impact on energy consumption, anticipated benefits from implementation, the CO<sub>2</sub> reduction potential, main parameters influencing implementation, cost estimation, and the conditions, barriers and constraints of implementation. For the more futuristic technologies, where quantification is difficult, a qualitative summary is provided instead, indicating those technologies felt to be promising for future implementation and emissions reductions potential. In these papers, only the anticipated impact on energy consumption and barriers to further development can be shown. In every paper, a range of potential thermal and electrical savings is provided – this range has been reached through consultation with technical experts. Where INR costs are indicated, approximate USD equivalent costs have also been given, using exchange rate USD 1 = INR 50.

## **'Low Carbon Technology Roadmap for the Indian Cement Industry' partner summaries**

### **Cement Sustainability Initiative (CSI)**

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

- ❖ Explore what sustainable development means for the cement industry
- ❖ Identify actions and facilitate steps cement companies can take, individually and as a group, to accelerate progress toward sustainable development
- ❖ Provide a framework for other cement companies to become involved
- ❖ Create the content and context for further stakeholder engagement

To date the CSI remains one of the largest global sustainability programs ever undertaken by a single industry sector. To find out more, visit [www.wbcscement.org](http://www.wbcscement.org)

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

### **International Energy Agency (IEA)**

The International Energy Agency (IEA) works to ensure reliable, affordable and clean energy for its 28 member countries and beyond. Founded in response to the 1973/4 oil crisis, the IEA's initial role was to help countries coordinate a collective response to major disruptions in oil supply through the release of emergency oil stocks to the markets. While this continues to be a key aspect of its work, the IEA has evolved and expanded to help enable the transition to a sustainable low-carbon energy future. It is at the heart of global dialogue on energy, providing reliable and unbiased research, statistics, analysis and recommendations. [www.iea.org](http://www.iea.org)

### **Confederation of Indian Industry (CII)**

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

CII is a non-government, not-for-profit, industry led and industry managed organization, playing a proactive role in India's development process. Founded over 116 years ago, it is India's premier business association, with a direct membership of over 8,100 organizations from the private as well as public sectors, including Small and Medium Enterprises (SMEs) and multinationals, and an indirect membership of over 90,000 companies from around 400 national and regional sectoral associations. [www.cii.in](http://www.cii.in)

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

## **National Council for Cement and Building Materials (NCB)**

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

## **IFC**

IFC, a member of the World Bank Group is the largest global development institution focused exclusively on the private sector. We help developing countries achieve sustainable growth by financing investment, providing advisory services to businesses and governments, and mobilizing capital in the international financial markets. In fiscal 2011, amid economic uncertainty across the globe, we helped our clients create jobs, strengthen environmental performance, and contribute to their local communities - all while driving our investments to an all-time high of nearly \$19 billion.

For more information, visit [www.ifc.org](http://www.ifc.org)

## **IFC in South Asia**

To grow opportunities for the underserved, IFC in South Asia has concentrated on low-income, rural, and fragile regions while building infrastructure and assisting public-private-partnerships; facilitating renewable energy generation; promoting cleaner production, energy and water efficiency; supporting agriculture; creating growth opportunities for small businesses; reforming investment climate; encouraging low-income housing; and making affordable healthcare accessible.

Through these strategic interventions in the region, IFC aims to promote economic inclusion at the base of the pyramid, particularly in the low income states of India; help address climate change impacts; and encourage global and regional integration including promoting investments from South Asia into Africa. In South Asia, IFC works in low-income and frontier regions where our work results in quick outcomes and strong impacts. To promote inclusive growth at the base of the pyramid, we built on previous years experiences to engage in working with the private sector in the region to develop measures that will increase incomes for the poor and small businesses.

IFC tries to support projects that are difficult in nature, first of its kind and reform oriented. We are increasingly being engaged by governments when they see we bring unique knowledge, experience and access to a wide network of investors, and sector expertise.

IFC's Sustainable Business Advisory promotes sustainable business practices specifically among firms in infrastructure, extractive industries, manufacturing, agribusiness, and services sectors. We offer these programs to companies to promote sustainable management and investment practices to create value and growth while addressing climate change through encouraging mitigation and building resilience. IFC's Resource Efficiency teams work with firms to save costs, prevent waste, and reduce green house gas emissions through more efficient use of energy, water, and materials. At the sector level, we promote broader adoption of good practices through case studies and benchmarking energy, water, and material use.



## Disclaimer

These papers are the result of a collaborative effort between members of the WBCSD Cement Sustainability Initiative (CSI) and a wide range of external stakeholders with technical expertise provided by the Confederation of Indian Industry (CII) and the National Council for Cement and Building Materials (NCB). External stakeholders were consulted on the technology papers and comments received are reflected here.

The individual member companies that make up the CSI, and their subsidiaries, have participated in the development of these papers in strict compliance with applicable competition laws. No specific commitments on implementation of any technologies described in the papers have been made. Users of the papers shall make their own independent business decisions at their own risk and, in particular, without undue reliance on this report.

This publication may contain advice, opinions, and statements of various information providers and content providers. IFC does not represent or endorse the accuracy or reliability of any advice, opinion, statement or other information provided by any information provider or content provider, or any user of this publication or other person or entity.

## Input to technical papers

Experts in many organizations inputted to the technical papers, including (in alphabetical order):

**Industry Co-chairs:** KN Rao (ACC), Dominic Fernandes (ACC), R Bhargava (Shree Cement), Daniel Raju (Shree Cement), L Rajasekar (UltraTech), SK Herwadkar (UltraTech)

**Industry Working Group:** Sandeep Shrivastava (Ambuja Cements Ltd), Jitander Kumar (HeidelbergCement India), Sanjay Jain (Lafarge), Sajid Khan (My Home Industries Ltd / CRH), AP Gupta (Shree Digvijay Cement – Cimpor Group), R Gopi (Zuari Cement)

**Cement Sustainability Initiative (CSI):** Caroline Twigg

**Confederation of Indian Industry:** Kiran Ananth, K Muralikrishnan, KS Venkatagiri

**National Council for Cement and Building Materials:** SK Chaturvedi, SNM Khan, Pradeep Kumar, AK Mishra, YP Sethi

**IFC:** Michel Folliet, Alan Miller, Yana Gorbatenko, Sushil Anand, Rajesh Miglani, Sivaram Krishnamoorthy

Expertise was also provided by numerous organizations including ABG Cement, ACC Techport, ATS Conveyors, Birla Corporation, Bureau of Energy Efficiency (GoI), Bureau of Indian Standards (GoI), Cement Manufacturers' Association (CMA), Chemtrols Industries Ltd, CP Consultants Ltd, Central Pollution Control Board (GoI), Dalmia Bharat Cement, Danfoss, Department of Industrial Policy and Promotion (GoI), Emergent Ventures India Ltd, Ernst and Young, Flaktwoods, Gujarat Sidhee Cement, Holtec Consulting Pvt, IKN, India Cements, Institute for Industrial Productivity, International Energy Agency, Jaypee Group, JFE Engineering, Loesche India, Ministry of Science and Technology (GoI), Reliance Cement, Schneider Electric, Shakti Sustainable Energy Foundation, Thermax India, Thyssenkrupp Industries India, Transparent Energy Systems, The World Bank.

## Overview of the Indian cement industry

The Indian cement industry, the second largest after China, has achieved an installed capacity of around 300 million tonnes (2011) and is anticipated to reach 320 million tonnes by 2012 and 600 million tonnes by 2020. With 99% of the installed capacity using dry process manufacturing, the Indian cement industry has been adopting latest technologies for energy conservation and pollution control as well as online process and quality control based on expert systems and laboratory automation.

On the energy conservation front, the best levels achieved by the Indian cement industry, at about 680 kcal/kg clinker (cli) (2.85 GJ/ton clinker) and around 66 kWh per tonne cement, are comparable with the best achieved levels in the world. However, a large number of plants installed before the 1990s are operating at relatively high energy consumption levels. Although some of these legacy plants have been modernized to a limited extent by retrofitting new technologies, they should, on priority, bring their energy consumption levels closer to the best achieved levels in the industry by further modernization and adoption of best available processes and technologies.

On the technological front, India's cement industry has largely adopted the state-of-the-art manufacturing technologies. However, systems for cogeneration of power through waste heat recovery and technologies for low NO<sub>x</sub> and SO<sub>x</sub> emissions have not penetrated significantly.

The industry's efforts towards emissions control, preservation of ecology and voluntary initiatives, such as Corporate Responsibility for Environmental Protection (CREP) are laudable. The Indian cement industry deserves commendation for its long-standing efforts towards reduction of its carbon footprint by adopting the best available technologies and environmental practices. This is reflected in the industry's achievement of reducing CO<sub>2</sub> emissions to an industrial average of about 0.719 tonne CO<sub>2</sub> per tonne of cement (direct and indirect emissions from Scope I and Scope II) from a substantially higher level of 1.12 tonne CO<sub>2</sub> in 1996.

The initiatives adopted by the Indian cement industry towards utilization of secondary materials are evident from the fact that production of blended cements (Portland Pozzolana Cement (PPC) and Portland Slag Cement (PSC)) in the country in the year 2010-11 was as high as 67%, as against only 36% in 2000-01. India's cement industry annually consumes around 45 million tonnes of fly ash from thermal power plants, as well as consuming the entire quantity of around 10 million tonnes of granulated blast furnace slag generated by steel plants in the country.

The cement industry has also sharpened its focus on the utilization of alternative fuels by increasingly using newer industrial, municipal and agricultural wastes. There is a substantial scope to enhance waste utilization, particularly hazardous and combustible wastes, and the industry is soon expected to achieve international best practices of waste utilization.

Possibilities of implementation of the technologies covered in these technical papers will depend on existing plant technology, layout and site constraints. The extent of reduction by implementing these technologies will also depend on several influencing parameters such as availability and quality of AFR, raw materials properties, etc. Therefore all the technical papers may not be applicable to any given facility. The maximum greenhouse gas emission reduction potential of each lever is only indicative and may or may not be fully achievable for all facilities. Therefore simply adding up the reduction potential of each technology in order to calculate total potential may not be appropriate

## Best Available Technologies (BAT) for a modern cement plant

### Introduction

India is the world's second largest cement producing country after China. In 2000, the country's annual capacity was around 120 million tonnes, and, a decade later in 2011, it is estimated to be around 300 million tonnes. This shows a cement capacity growth rate of approximately 10% every year. The Indian cement industry is far more advanced than many other countries in specific energy consumption in both thermal and electrical energy (energy use per unit of production). (Best achieved numbers being 680 kcal/kg of clinker (2.85 GJ/ton clinker) and 66 kWh / tonne of cement). Many plants have already retrofitted or have chosen a better design at the commissioning stage itself, thereby creating a better platform for enhancing energy efficiency. For a modern cement plant with the best available technology, the following features have to be taken into consideration:

### Mines<sup>1</sup>

For medium and soft materials, a surface miner with single stage impact crusher and wobblers can be chosen, whereas for hard materials, conventional mining with two-stage crushing can be selected. Advanced mining with mine plan software would result in reduced raw material additives, over-burden handling and enhanced mine life. Overland conveyors to transport crushed limestone will be beneficial for long distance transport between mines and plants.

Other mine management measures are the installation of mobile crushers for productivity improvement, and radio controlled mines machinery monitoring system for better control and optimization.

**Crusher discharge:** a cross belt analyzer can be installed to ensure the quality and to enhance the mine's life. Stacker and reclaimer with higher blending ratio (of 10:1) can be adopted by design.

### Raw Mill

- ❖ For limestone with a moisture content of more than 5% and hardness classified as medium to soft, Vertical Roller Mills (VRM) with the latest generation classifier are being installed with the following:
- ❖ Mechanical recirculation system
- ❖ High efficiency fans with High Tension (HT) Variable Frequency Drive (VFD)
- ❖ Automatic sampler and cross-belt analyzer in the mill feed for better quality control
- ❖ Adaptive predictive control for mill operation

For limestone with low moisture content (less than 3%), roller press with separator in finished mode can be installed with the following:

- ❖ High efficiency separators and cyclones
- ❖ Automatic sampler and cross-belt analyzer in the mill feeding for better quality control
- ❖ Adaptive predictive control for mill operation

### Silo

- ❖ Continuous blending silo with high blending ratio (10:1)
- ❖ Mechanical conveying system for all material transport
- ❖ For silo extraction, gravimetric feeding system for all fine material with an accuracy of over 1%

<sup>1</sup> In India, 'Mine' refers to both open cast / surface mine (in Europe, this is 'quarry') and underground mine

## Pyro-processing

### Preheater

- ❖ A six stage or seven stage preheater is used wherever the heat from preheater and cooler is sufficient to dry fuel and raw material
- ❖ Cyclones with high efficiency and low pressure drop
- ❖ Low NO<sub>x</sub> calciner with adequate residence time for increased Alternative Fuel and Raw materials (AFR) use in calciner
- ❖ HT VFD for preheater fans

### Kiln

- ❖ Multi-channel burner for improved thermal efficiency, flexibility of firing AFR, better flame control and low NO<sub>x</sub> emissions
- ❖ High strength insulation bricks in kiln inlet and calcining zone
- ❖ Kilns operating with high peripheral speed (up to 6 – 7 RPM)
- ❖ VFD control for shell cooling fans

### Coolers

- ❖ Latest generation coolers with a total loss of less than 100 kcal/kg clinker, and a recuperation efficiency of about 78%
- ❖ High efficiency aerofoil bladed cooler fans with VFD

### Control system

- ❖ Adaptive predictive control system
- ❖ Online NO<sub>x</sub> control
- ❖ Online flame control
- ❖ Online frelime control
- ❖ Flow measurement with advanced techniques

### Alternative Fuel and Raw materials (AFR)

With a strong focus on increased AFR usage, it is necessary for newer cement plants to consider AFR storage, handling and feeding system by design. The extent of achieving a specific Thermal Substitution Rate (TSR) would, however, depend on the availability of AFR in the region, and on economic and technical feasibility. Newer cement plants should therefore be designed with adequate provision not only for present TSR consideration, but should also permit future scalability and retrofits; lest it becomes a bottleneck for accelerated AFR usage.

## **Coal mill**

- ❖ Stackers and reclaimers with high blending efficiency to use different coal grades with alternative fuel
- ❖ Vertical roller mill for grinding
- ❖ Gravimetric feeding system
- ❖ Hot gas source from preheater to ensure safety and coal drying
- ❖ Coal mill fans with VFD and high efficiency
- ❖ High pressure blowers for fine coal transportation with increased phase density

## **Cement mill**

Preferred options for cement grinding could be among

- ❖ Vertical roller mill for grinding using cooler vent air as the hot gas source
- ❖ Roller press and ball mill combination with high efficiency separator
- ❖ Roller press in finish mode

## **Packing plant**

- ❖ Cement silo extraction with air slide and blower
- ❖ Electronic packers
- ❖ Double-decker wagon loader
- ❖ Provision for bulk dispatch and bag dispatch, depending on plant context (e.g., rural or urban location)

## **Minimal Waste Heat Concept**

While the current trend among cement plants is to adopt WHR systems by design or retrofit, future cement plants are expected to see the emergence of a minimal waste heat recovery concept, wherein suitable system design and technology developments would ensure elimination of all waste heat generated from the system itself. Experts strongly predict that this system would be far more efficient than utilizing the waste heat for power generation as in present cement plant designs.

## **Dust Control Equipment**

The installation of pulse-jet baghouses with membrane bags for all process applications, and pulse-jet bag filters with non-membrane bags for non-process applications. For clinker coolers, either Electrostatic Precipitator (ESP) or bag filters with a Waste Heat Recovery (WHR) system can be installed.

## **Technical paper no.1: Electrical and thermal energy efficiency improvements in kilns and preheaters**

### **Current status**

Kiln and preheater system in Indian cement industry has achieved very high levels of technology adoption and energy efficiency levels. With significantly higher productivity levels and installation of latest energy efficiency and automation control devices, these systems are operating at one of the best performance measures in the world.

India's modern cement plant is equipped with six stage (or five stage in certain clusters having higher moisture levels in limestone) preheater with in-line or separate-line calciner (depending on the rated kiln output), kilns with volumetric loading of about 5--6.5 tpd/cu.m and advanced automation systems. Continuous Emission Monitoring Systems (CEMS) are also being increasingly adopted in new as well as existing kilns. However, while the productivity levels of existing kilns have been increased to meet growing demand, enhanced energy consumption due to increased velocity resulting in higher pressure drop and reduced heat transfer offers potential areas for improvement.

The installation of high efficiency (and low pressure drop) cyclones offers significant energy efficiency improvement opportunity in cement kilns. With several design innovations, a six-stage preheater system offers pressure drop of about 300 mmWC in latest designs. For existing plants, installation of additional preheater stages (wherever civil structures permit from 4/5 stages to 6/7 stages) for increased heat recovery and computational fluid dynamics (CFD) studies for reducing the pressure drop in preheater cyclones, along with necessary modifications offer further electrical and thermal energy efficiency improvement opportunities.

With several advancements in refractory properties, such as thermo-mechanical and alkali resistance, cement kilns today can minimize the radiation losses as well as handle increased AFR substitution rates. The kiln main drive is also undergoing substantial improvements with better gears and lubrications system. Automation and control systems, such as adaptive-predictive control systems and online control systems for flame, free-lime, inlet NOx are very effective for better throughput, smooth operation and control.

Oxygen enrichment as an option for energy efficiency (by reducing the combustion air requirements) as well as increased alternative fuel utilization (for kiln firing fuels, by providing better flame temperature and ensuring complete combustion) can offer significant energy efficiency, as well as assist in increased substitution rates. Higher investment costs for installing oxygen separation system from air, storage and handling systems and the related safety issues are the deterrents, affecting the economics of increased adoption of oxygen enrichment in the Indian cement industry today.

## Technology proposed

- ❖ Low pressure drop and high efficiency cyclones
- ❖ High tension variable frequency drive for precise control of preheater fans
- ❖ Computational Fluid Dynamics (CFD) studies to reduce the pressure drop and improve energy efficiency
- ❖ Installation of additional preheater stages in older kilns
- ❖ Improved insulation for minimizing radiation loss in kiln and preheater sections
- ❖ Adaptive-predictive control systems for precise control of kiln system, increased productivity and better energy efficiency
- ❖ Online automation systems for flame control, free-lime and inlet  $\text{NO}_x$ , among others
- ❖ Installation of additional preheater string for energy efficiency and productivity increase requirements
- ❖ Online thermograph scanning and triggering corrective action to reduce kiln heat loss

## Future technologies (under R&D)

The Indian cement industry is also keen to explore emerging developments, using kilns with zero waste heat concept (design to utilize all waste heat in process itself without a separate WHR system), heat recovery from kiln shell radiation, fluidized bed combustion kilns, cogeneration of cement and power, limestone enrichment technology (for utilizing low grade limestone), and so on when it emerges from design to pilot/implementation stage. These practices are expected to elevate the Indian cement industry's energy and productivity performance levels to greater heights.

## Anticipated benefits

Thermal savings: 15 – 20 kcal/kg clinker

Electrical savings: 2 – 3 kWh/mt clinker

$\text{CO}_2$  reduction potential (direct and indirect): 7 – 10 kg  $\text{CO}_2$ /mt clinker

## Primary influencing parameters

- ❖ Present level of technology adoption and specific energy consumption
- ❖ Raw material moisture
- ❖ Need for increased throughput from existing kiln
- ❖ Electric power and fuel cost
- ❖ GHG intensity of present power generation and fuel combustion

## Cost estimation

- ❖ Depending on the extent of absorbing the technology proposed and the influencing parameters, cost could vary between INR 20 million to 60 million (approximately USD 400,000 to USD 1.2 million)

## Conditions, barriers and constraints

### Technical

- ❖ Layout constraints/civil structural capability for stage addition
- ❖ High moisture limestone restricts the number of stages in the preheater
- ❖ Burnability of raw mix

### Policy

- ❖ India's stringent environmental norms, necessitating installation of additional equipment, might increase future energy consumption
- ❖ Logistics/availability and quality concerns of coal, and quality concerns of raw materials and power among others

### Financial

- ❖ Longer shutdown time for major modifications
- ❖ Extended return on investments for certain initiatives, if only energy efficiency benefits are taken into account
- ❖ Higher investment and operating costs for oxygen enrichment



## Technical paper no. 2: Latest generation high efficiency clinker coolers

### Current status

The Indian cement industry, over the last several years, has increasingly adopted reciprocating grate coolers with great success. While rotary coolers have been completely phased out, several installations with planetary coolers are still in vogue. With more than 50% of cement produced from kilns less than 10 years old, reciprocating grate coolers have become common practice in the industry today, with cooler loading of about 45–50 tpd/square metre (m<sup>2</sup>) of cooler area. Enthalpy from hot clinker is recovered to preheat the incoming secondary and tertiary air to improve thermal efficiency. Based on the cooling efficiency, technology adopted, and desired clinker temperature, the amount of air used in this cooling process is approximately 2.5–3 kg/kg of clinker.

Conventional grate coolers provide a recuperation efficiency of 50–65%, depending on the mechanical condition and process operation of the cooler. This corresponds to a total heat loss from the cooler of about 120–150 kcal/kg clinker. Several cement kilns in India, as a result of continuous productivity increase measures, are operating at significantly higher cooler loading range than rated, with a range of 50–65 tpd/m<sup>2</sup> of cooler area; increasing the total heat loss from the cooler.

The reciprocating cooler has undergone significant design developments; the latest generation clinker coolers offering better clinker properties, and significantly lower exit gas and clinker temperatures. As a direct consequence, secondary and tertiary air temperatures offered by latest generation coolers have also increased to about 1,250°C and 1,000°C, respectively. The cooling air requirements of such coolers have also gradually reduced to about 2.2–2.4 kg/kg clinker.

While it is very attractive to adopt latest generation coolers for new plants by design, retrofitting existing conventional reciprocating coolers with latest generation coolers also offers a significant potential for electrical and thermal energy saving in the Indian cement industry. The total heat loss of latest generation clinker coolers is less than 100 kcal/kg clinker, and has a recuperation efficiency in the range of 75–80%.

### Future technologies under development

With increasing thermal efficiency in the kiln and preheater system, it is necessary for clinker coolers to be capable of supplying reduced secondary and tertiary air volumes with higher recuperation efficiency. Several improvements in clinker cooler technology in terms of better air distribution for reduced cooling air requirement, effective conveying system for better transport of clinker and mechanical stability of cooler, optimum under-grate pressure and heat shields, are under development. Vertical shaft coolers with recuperation efficiencies of more than 80% are under development which could further result into specific heat and CO<sub>2</sub> reduction. The Indian cement industry can therefore expect further reductions in cooler heat loss and increased energy efficiency.

### Anticipated benefits

Thermal savings: 10–30 kcal/kg clinker

Electrical savings: 0–1 kWh/mt clinker

CO<sub>2</sub> reduction potential (direct and indirect): 8–10 kg CO<sub>2</sub>/mt clinker

## Primary influencing parameters

- ❖ Current type of cooler used and its specific energy consumption
- ❖ Need for increased throughput
- ❖ Requirement of higher secondary and tertiary air temperature
- ❖ Electric power and fuel cost

## Cost estimation

- ❖ New installation: INR 100 – 150 / tonne of clinker (approximately USD 2 – 3 / tonne of clinker)
- ❖ Retrofit: INR 200 – 250 / tonne of clinker (approximately USD 4 – 5 / tonne of clinker)

## Conditions, barriers and constraints

### Technical

- ❖ Uncertainty in estimating the guaranteed benefits for retrofit installations
- ❖ Additional shutdown time requirement for retrofits

### Policy

- ❖ None to date

### Financial

- ❖ Higher investment costs: incremental cost in case of new installation and overall cost in retrofit installation

## Technical paper no. 3: Energy efficiency in grinding systems

### Current status

Material grinding is the largest electrical energy consumer in cement manufacture. Therefore the Indian cement industry, where energy costs contribute to a majority share in overall cement manufacturing costs, has adopted the most energy efficient technology for its grinding requirements.

For raw material grinding, the most commonly used grinding technology is Vertical Roller Mills (VRM), while few older facilities still operate with either ball mills alone or ball mills with pregrinder (the most commonly used pregrinder is the mechanical crusher). Coal grinding has also gradually shifted to VRM use, while a few older facilities still operate with air-swept ball mills. With an increased use of petroleum coke and imported coal and, therefore, enhanced coal fineness requirements, VRMs are gradually becoming the most preferred option for coal mills.

India's cement grinding uses has multiple grinding systems: ball mills; ball mills with pregrinder (the commonly used pregrinders are High Pressure Grinding Rolls (HPGR) followed by vertical mills as a pregrinder to ball mills); VRM for clinker grinding and, in certain grinding locations, ball mills and VRM (grinding clinker and additive materials separately and blending).

The newest plants in the Indian cement industry (installed in the last 10 years and contributing over 50% of cement manufacturing capacity) have VRM for raw material and coal grinding and VRM/ball mill with HPGR for cement grinding.

The selection of grinding mill type depends mostly on the moisture content and material hardness. VRM, widely accepted for the combined drying and grinding of moist raw materials and coal and for low energy consumption, has been widely used for all three grinding requirements. Several improvements in design and operation of the mill and other equipment in the grinding circuit are resulting in less energy consumption and improved reliability.

The introduction of an external re-circulation system for material, adjustable louvre ring, latest generation classifier and modification of mill body to improve the air and material trajectories are examples of such changes which increase throughput and improve energy efficiency.

While VRM has been the preferred option for raw material and coal grinding, clinker grinding still provides several options for Indian cement manufacturers. The closed circuit ball mill with high efficiency separator is the most common type of clinker grinding system used. A comparative analysis of various options available for cement grinding compared to a closed circuit ball mill is provided below:

## Comparative analysis

No.	Parameters	Base case	Alternative 1	Alternative 2	Alternative 3
		Closed Circuit Ball Mill (CCBM)	Semi finish grinding – ball mill and HPGR pregrinder	HPG finish mode	VRM
1.	Comminution technique	Impact and attrition with the grinding balls	Compression in RP. Attrition in ball mill	Compression	Compression
2.	Feed size	90% passing 25 mm sieve	Up to 2 times the gap width	Up to 2 times the gap width	Up to 75 mm
3.	Air flow requirement	Low	Low	Low	High
4.	No. of auxiliary equipment	More	More	Less	Less
5.	Maintenance	Low	High	High	Medium
6.	Expected specific power consumption, kWh/t OPC @ 3,400 cm <sup>2</sup> /gm	32 – 34	26 – 28	26 – 28	24 – 26
7.	Ease of operation	High	Medium	Medium	Low

## Anticipated benefits

Thermal savings: nil

Electrical savings: 6 – 10 kWh/mt cement

CO<sub>2</sub> reduction (indirect): 7 – 12 kg CO<sub>2</sub>/mt cement

## Primary influencing parameters

- ❖ Material (raw material, coal and clinker) properties
- ❖ Output size requirement (fineness and particle size distribution and so on)
- ❖ Material science and grinding technology
- ❖ Durability of construction material (reliability and maintenance, among others)

## Cost estimation

Since cost estimation for individual mills for various grinding requirement is difficult, a typical cost estimate is compared below:

- ❖ Ball mill with closed circuit: X (X given as an example unit)
- ❖ Vertical roller mill (VRM): 2.3 – 2.5 X (that is to say, 2.3–2.5 times more than ball mill)
- ❖ Roller press in finish mode: 1.8 – 2 X (that is to say, 1.8–2 times more than ball mill)
- ❖ Roller press with ball mill: 2 – 2.2 X (that is to say, 2–2.2 times more than ball mill)

## Conditions, barriers and constraints

### Technical

- ❖ Roller press circuit could have a capacity limitation, whereas higher capacity is possible with VRM
- ❖ Additional fundamental research in material science is required

### Policy

- ❖ Absence of policy standards linking strength and fineness with application

### Financial

- ❖ Retrofit costs to upgrade grinding technology is very high; long payback periods (of about 6-10 years) if only energy savings are considered

## **Technical paper no. 4: Retrofit uni-flow burner with advanced multi-channel burner**

### **Current status**

Increased focus on energy efficiency and preparedness for increased alternative fuel utilization has resulted in the Indian cement industry gradually shifting from uni-flow (or mono-channel) burners to multi-channel burners. Several cement kilns have installed multi-channel burners either by design or as a retrofit in their pursuit of energy efficiency improvements.

Few cement facilities in India still operate with uni-flow burners. A uni-flow burner, a simple refractory-lined single pipe with a nozzle, has primary air and fuel conveyed together for combustion in the rotary kiln. Uni-flow burners offer very little operational flexibility, their exit velocities (determined by the nozzle diameter) at the tip of the burner cannot be varied according to the changing fuel feed rate, have a high primary air ratio compared to multi-channel burners, and are unable to utilize diverse alternative fuels.

Compared to a simple uni-flow burner, modern multi-channel burners offer better possibilities for flame shape control because of their separate primary air channels (swirl air and axial air). This allows for the adjustment of primary air amount and injection velocity, independent of the coal injection. The most important flame control parameters are primary air momentum (primary air quantity in percentage multiplied by nozzle velocity) and amount of swirl (tangential air discharge). A high momentum will give a short, hard flame, whereas a low momentum will make the flame longer and lazy. Swirl will help create recirculation in the central part of the flame, stabilizing the flame and giving a short ignition distance. Higher swirl, however, can cause high kiln shell temperatures due to flame impingement on the burning zone refractory. A good swirl control system is therefore important. The best solution would be a system wherein swirl could be adjusted independent of the momentum. Most modern multi-channel burners therefore have adjustable air nozzles.

Alternative fuel utilization is still low in India: the average Thermal Substitution Rate (TSR) is less than 1%. However, several cement facilities have gradually increased the TSR in cement manufacture, some plants recording a peak TSR of up to 12%. With increased focus on higher TSR, multi-channel burners will become an imperative to help facilities manage the variety and complexity of alternative fuels.

Compared to a conventional burner, modern multi-channel burners offer much better possibilities for flame shape control, a high momentum, and the flexibility to use different types of fuels, such as liquid or solid biomass. Advanced burners reduce the loss in production during kiln disturbances and also reduce NO<sub>x</sub> in the burning zone as the primary air ratio is low. NO<sub>x</sub> emissions can be reduced as much as 30–35% over emissions from a typical direct fired, uni-flow burner. Better flame properties with the multi-channel burner improve combustion efficiency and eliminate flame impingement on refractory.

### **Future technologies (under R&D)**

While multi-channel burners are becoming increasingly common in the Indian cement industry today, they might need greater innovation and better design to suit the requirements of an increased TSR of 30% or more. The latest research on plasma burners could also be an opportunity for Indian cement industry to explore the dual benefits of increased AFR utilization and higher energy efficiency. Additionally, the installation of online flame scanners and burning zone controllers play an important role in optimization.

## Anticipated benefits

Thermal savings: 3 – 5 kcal/kg clinker

Electrical savings: 0 – 0.5 kWh/mt clinker

CO<sub>2</sub> reduction: 2 – 4 kg CO<sub>2</sub>/mt cement

## Primary influencing parameters

- ❖ Recuperation efficiency of clinker cooler
- ❖ Energy efficiency and throughput increase considerations
- ❖ Extent of utilization of alternative fuels
- ❖ Kiln capacities
- ❖ Present electrical and thermal energy cost

## Cost estimation

New installation of burner: INR 20 – 30 million per kiln (approximately USD 400,000 – 600,000 per kiln)

## Conditions, barriers and constraints

Technical

- ❖ Layout constraints can pose certain barriers in some facilities

Policy

- ❖ None to date

Financial

- ❖ High retrofit costs and long payback periods to replace uni-flow with multi-channel burners

## Technical paper no. 5: Energy efficiency improvement in process fans

### Current status

Process fans are large electrical energy consumers in cement manufacture, second largest to grinding. India's cement industry has focused on process fans for several years in its pursuit for increased energy efficiency, and has reduced operating costs in the process. Modern cement industry fans are designed for higher energy efficiency, higher wear resistance, lower material build-up and effects of erosion, better speed control, low vibrations and high operational stability.

In a number of plants, high energy efficient fans have replaced inefficient process fans by both design and by retrofit of energy saving speed control devices, eliminating the control damper have been a regular feature in several plants. Higher pressure drops in inlet and outlet duct systems can be analyzed and reduced by using CFD techniques. A few of the widely used process fans, such as preheater fans, raw mill fans, coal mill fans, cooler fans, and so on consume over 40% of the total electrical energy in cement manufacture. With better construction materials for fans and with design optimization, fans with a higher operating efficiency are available for all cement industry applications.

Precise design specifications, reduced margins between requirement and procurement, and a choice of appropriate control systems can offer a significant energy saving opportunity. Several studies indicate that excess margins buffered in at various levels are one of the major reasons for deviation between design specifications and operating requirements. Experts suggest that optimum margins for capacity and heat should not be over 10%, resulting in an enhanced power consumption of about 25%. To curtail this margin and offer precise process controls, the choice of an appropriate speed control device becomes essential. Speed control is the most effective way of capacity control in centrifugal equipment; the choice of right speed control mechanism offers additional margins for efficiency improvements.

Among the various options available for speed control of High Temperature (HT) process fans, such as Grid Rotor Resistance (GRR) control, Slip Power Recovery Systems (SPRS), and so on. HT Variable Frequency Drives (VFD) are found to be the most suitable speed control mechanism, considering the precise control offered and the low inherent system energy losses. Hence, for all major fans, the right selection of fan with HT VFD as a preferred speed control offers the maximum energy saving. Wherever VFDs are installed, the elimination of control damper is preferred. However, wherever the process needs damper control, a low pressure drop damper can be installed, such as aerofoil multi-louvered damper for cooler fans.

For all other Low Temperature (LT) process fans, the benefits of installing LT VFD have been proven. The inherent margin that results in additional power consumption of up to 25% can itself pay back the cost of an LT VFD retrofitted for energy saving.



While emphasizing the operating efficiency of fans, it is important to consider the best available efficiencies offered to evaluate economics either by design or for a retrofit installation:

No.	Fans	Efficiency
1.	Preheater fan	82 –84%
2.	Raw mill fan	82 – 84%
3.	Cement mill separator fan	82 – 84%
4.	Cooler fans	> 80%
5.	All auxiliary and bag filter fans	> 75%
6.	Reverse air bag house fan	75 – 80%
7.	Cooler vent fan	75%

Process fans, with the efficiency levels mentioned above and with an appropriate speed control mechanism would be the preferred option for optimum energy efficiency. Retrofit to replace low efficiency fans with fans of higher operating efficiency, and the installation of appropriate speed control devices, is generally paid back by the energy saving these can deliver.

It is however important for the industry to constantly monitor the performance of existing fans, and to evaluate the cost economics for replacement. Whenever the return on investment meets the organizational norms, it is advisable to immediately replace existing fans with those of higher operating efficiency available at that time. . This will certainly help to significantly lower the overall cost of ownership of such process fans.

#### **Future technologies (under R&D)**

While several studies are underway to further improve the efficiency of process fans through better construction material, blade angles, gaps, entry velocities, etc, one promising research area underway looks at increasing the operating pressures of axial fans to replace centrifugal fans, wherever feasible. Axial fans offer significantly higher operating efficiencies than centrifugal fans, though the pressure rise of axial fans is significantly lower than of centrifugal fans. If axial fans could offer sufficient pressure rise to replace a centrifugal fan, this would certainly result in a significant lowering of power consumption with better operating efficiency.

#### **Anticipated benefits**

Thermal savings: none

Electrical savings: 4 – 6 kWh/mt cement

CO<sub>2</sub> reduction (indirect): 5 – 8 kg CO<sub>2</sub>/mt cement

#### **Primary influencing parameters**

- ❖ Present levels of energy efficiency and specific energy consumption
- ❖ Layout constraints
- ❖ Cost of electrical energy

## Cost estimation

- ❖ Cost for HT VFD: INR 12,000 – 15,000 / kW (approximately USD 240 – 300 / kW)
- ❖ Cost for LT VFD: INR 6,000 – 10,000 / kW (approximately USD 120 – 200 / kW)
- ❖ Cost for fan: INR 4,000 – 6,000 / kW (approximately USD 80 – 120 / kW)

## Conditions, barriers and constraints

### Technical

- ❖ Layout constraints can pose certain barriers in few facilities, where the ideal duct system cannot be accommodated

### Policy

- ❖ None to date

### Financial

- ❖ Retrofit costs in some cases could be high

## **Technical paper no. 6: Energy efficiency improvement in auxiliary equipment in the cement manufacturing process**

### **Current status**

Auxiliary equipment such as conveyors, elevators, blowers, compressors and pumps, consuming about 10% of total electrical energy of cement manufacturing process, are vital for transporting the material and gases from one manufacturing stage to another. For enhanced energy efficiency, the optimum performance of auxiliary equipment becomes important within the overall energy performance of the manufacturing facility.

### **Technologies proposed**

#### **❖ Pipe conveyor**

Pipe conveyors can cause both horizontal and inclined curves in the material flow path. Due to this inherent characteristic, a single pipe conveyor can replace several traditional conveyors systems, removing the need for transfer points with relevant steel structures, dust control systems, and so on. Larger friction of material inside the tubular belt allows a higher slope angle of the conveyor: a single pipe conveyor can replace the combination of belt conveyor and bucket elevator. The cross-section of a pipe conveyor is smaller than the equivalent belt conveyor, therefore space requirements are minimal and the weight of structures and gantries is lower.

#### **❖ Centrifugal blower**

One of the latest advancements in the fine material transport system (fine coal feeding to kiln, calciner, fly ash and cement transport) is the use of a centrifugal blower, which has a higher design efficiency compared with conventional twin lobe blowers. It also comes with an inbuilt Variable Frequency Drives (VFD), which facilitates precise control and optimization of phase density (material to air ratio). With these changes, reductions of over 30% in specific power can be achieved.

#### **❖ Centrifugal compressor**

Centrifugal compressors are generally used for high capacity application i.e., compressed air requirement to more than 2,000 Cubic Feet per Minute (CFM). The specific energy consumption is lowest compared with other types (0.13kW/CFM at seven bar pressure against 0.17kW/CFM of screw compressor). With an increased demand of compressed air, it is beneficial to have a centrifugal compressor to cater to the base demand and achieve the lowest specific energy consumption.

#### **❖ VFD for pumps and screw compressors**

One of the best methods of capacity control is the use of VFD. The latest VFD has better reliability (available in both Low Temperature (LT) and High Temperature (HT) voltages), a higher operating range and reduced harmonics. The installation of VFD in the case of pumps can ensure zero recirculation and valve loss. VFD in a compressor can result in constant pressure (which improves the system reliability and stability), zero unloading, and therefore power reduction.

#### **❖ High efficiency pumps**

Pumps in the cement industry, although small energy consumers, can offer energy saving opportunities. The typical use of pumps (largely centrifugal) in the cement industry is for cooling applications, in Gas Conditioning Towers (GCT) (in a few plants) and transferring raw/fresh water to the facility. Studies in several plants indicate inefficiency on two accounts: mismatch between design parameters and operating requirements, and efficiency improvement by retrofitting with latest pumps.

### ❖ **Wobbler screen for crusher**

A wobbler feeder with a series of shafts installed before the crusher prevents the undersized material from feeding into the crusher, thereby avoiding the generation of excessive fine materials. They have been successfully operating with moisture content of less than 5% and the reduction in the specific energy consumption of the crusher can be as high as 0.5 kWh/mt of material.

### ❖ **Automation for auxiliary equipment**

It is gradually becoming a regular practice to incorporate automated auxiliary equipment, comprising pumps, bag filter fans and compressors. Such automation includes the interlocking of auxiliary equipment with the main process equipment; compressed air-purging based on a pressure drop across the bag filter; eliminating idle running, and controlling parameters like flow, pressure based on process variation/demand.

### **Anticipated benefits**

Thermal savings: none

Electrical savings: 0.5 – 1 kWh/tonne of cement

CO<sub>2</sub> reduction (indirect): 0 – 1 kg CO<sub>2</sub>/tonne of cement

### **Primary influencing parameters**

- ❖ Present levels of energy efficiency and technology adoption
- ❖ Cost of power
- ❖ Layout feasibility

### **Cost estimation**

- ❖ Cost for pipe conveyor: INR 80,000 – 100,000 / meter of length (approximately USD 1,600 – 2,000 / meter of length)
- ❖ Cost for LT VFD: INR 6,000 – 10,000 / kW (approximately USD 120 – 200 / kW)
- ❖ High efficiency pump: INR 4,000 – 10,000 / kW (approximately USD 80 – 200 / kW)
- ❖ Turbo blower: INR 23,000 – 27,000 / kW (approximately USD 460 – 540 / kW)

### **Conditions, barriers and constraints**

Technical

- ❖ Layout could pose certain constraints in implementing some of the proposed options

Policy

- ❖ None to date

Financial

- ❖ Higher investment and operating costs of latest auxiliary equipment could be a deterrent

## **Technical paper no. 7: Energy efficiency improvement in Captive Power Plants (CPP)**

### **Current status**

In its pursuit for reliable and high quality electrical power, over 53% capacity of India's cement industry has adopted CPP for their internal power requirements. The initial trend was to explore heavy oil-fired diesel generator sets to meet part demand in the event of grid failure. With a sharp rise in fuel oil prices and frequent outages of the grid, the industry has now completely shifted to coal / lignite and petroleum coke-based thermal power plants as the preferred CPP option. Additionally, multiple fuel and biomass approaches are in practice.

The estimated average auxiliary power consumption in cement industry CPPs ranges from 10–13%, whereas the best operating CPPs in the Indian cement industry operate at 5.8–6% of auxiliary power consumption. A similar range is also observed in the CPP heat rate; the average heat rate of all CPPs installed in the Indian cement industry is about 3,200 kcal/kWh, and in the range of 2,550–2,575 kcal/kWh in the better operating plants.

With such a large share of cement plants operating with CPP and leading to such a wide variation in auxiliary power consumption and heat rate values, this offers an excellent lever for energy efficiency improvement and Greenhouse Gas (GHG) emissions reductions. Energy efficiency in CPPs could be achieved in two ways: energy efficiency by design and energy efficiency by retrofit.

### **Energy efficiency by design**

With India's cement industry capacity expected to double in the next 10 years, and CPPs becoming integral to cement plants, energy efficiency by design for newer CPPs is imperative for low carbon growth of this sector. With coal still the preferred fuel source to power CPPs, and considering Indian coal's high ash content, the most suitable option would be to adopt the Circulating Fluidized Bed Combustion (CFBC) boiler with double/multiple (for increased heat rate) extracting turbine. Lack of availability of water might lead to the selection of Air Cooled Condensers (ACCs) by design in forthcoming CPPs. Installation of latest combustion control systems, speed control for major auxiliary equipment, such as boiler feed water pumps, Forced Draft (FD) fans and Induced Draft (ID) fans, auxiliary cooling water pumps and condensate extraction pumps and so on, would be essential by design. The target heat rate and auxiliary energy consumption values for newer CPPs should be 2,550 kcal/kWh and 6%, respectively.

### **Energy efficiency by retrofit**

Renovation and modernization of steam turbines: the first step in the Indian cement industry's pursuit for lower GHG emissions in its CPPs would be to carry out a complete steam path audit for relatively old turbines. Isentropic efficiency needs to be calculated and, depending on the results, refurbishment / replacement of the turbines can be evaluated.

### **Circulating Fluidized Bed Combustion System (CFBC) in place of Atmospheric Fluidized Bed Combustion System (AFBC)**

The most commonly used boilers across CPPs are either AFBC or CFBC. Among the two, the latter is designed to work with a higher ash content coal, which is better suited for the Indian cement industry (Indian coal typically has high ash content). It also results in a lower loss on ignition (LOI) and lower SO<sub>x</sub> and NO<sub>x</sub> emission levels. Its capacity ranges (usually available) are 65–250 tph and it has an efficiency of about 88–90%. Usually AFBC boilers do not have efficiencies more than 84–85%. CFBC also has multi-fuel firing capability (70% coal and 30% alternative fuel). The burner system and fluidization system can also be modified to improve combustion efficiency and thereby reduce the LOI in fly ash.

## **Vacuum pumps**

Steam ejectors are widely used for maintaining a vacuum inside the condenser. The steam for its operation is usually supplied from a Pressure Reducing and De-superheating System (PRDS), which reduces the main steam pressure to the operating pressure of the ejector. But by doing so, motive steam, that has the potential to generate more power, is lost. Ejectors could be powered from the steam at low cost or can be replaced completely with a vacuum pump.

## **Use of low grade steam for Vapor Absorption Machine (VAM)**

VAMs are normally available above 100 TR (tonne of refrigeration). The installation of VAM is completely site-specific, and local cost economics must be taken into consideration (steam cost and electricity cost) in feasibility assessment.

## **Use of VFD in equipment with higher load variation**

Most energy intensive equipment is over-designed and is controlled by means of dampers and control valves. Energy loss (due to pressure loss across the control system) can be avoided by optimizing the pressure with variable frequency drives. For example, VFD can be used to optimize the flow in Condensate Extraction Pump (CEP), Boiler Feed Pump (BFP), Cooling Water Pump (CWP) and Auxiliary Cooling Water Pump (ACWP) (water side) and Primary Air (PA) fans, FD fans and ID fans (air and gas side).

Avoiding steam leakages: steam leakage is a visible indicator of waste and must be avoided. Steam leaks on high pressure mains are prohibitively costlier than on low pressure mains. In fact, the plant should consider a regular surveillance program for identifying leaks at pipelines, valves, flanges and joints. By plugging all leakages, fuel savings may be high, reaching up to 5% of the steam consumption in a small or medium scale industry, or even higher in installations with several process departments.

Air Cooled Condensers (ACCs) are typically observed in cement industry CPPs due to shortage of water. Optimizing ACCs by periodic performance evaluation, utilization of coil mesh type water sprinkling systems and adoption of Fiber Reinforced Plastic (FRP) blades for cooling tower fans (for its better aerodynamic profile and thereby lower energy consumption) and so on, could provide opportunities for CPPs to maintain or improve the performance of the ACCs and thereby of the complete CPP.

Integrating CPP with the cement plant: considering its close proximity to cement manufacturing facilities, a CPP can explore all possible opportunities for WHR for its preheating applications. Preheating of make-up water or of boiler feed water can be carried out by utilizing waste heat sources in the cement process, such as cooler vent gases (typically at 250–300°C), preheater hot gases (typically ranging around 280–350°C) and kiln shell radiation loss. Wherever the WHR option is still not explored, heat recovery to partially meet the CPP requirement offers an excellent opportunity at some cement plants.

## **Anticipated benefits**

Thermal savings: 100 – 250 kcal/kWh

Electrical savings: 20 – 30 kWh/mw of CPP capacity

CO<sub>2</sub> reduction: 0.05 – 0.1 kg CO<sub>2</sub>/kWh

## Primary influencing parameters

- ❖ Present level of technology adoption in CPPs
- ❖ Cost of coal, thereby CPP generated power
- ❖ CO<sub>2</sub> intensity of fuel
- ❖ Availability of water for cooling requirements
- ❖ Plant Load Factor (PLF)

## Cost estimation

Depending on the extent of absorbing the technology proposed and the influencing parameters, cost could vary between INR 10 million and 30 million (approximately USD 200,000 – 600,000)

## Conditions, barriers and constraints

### Technical

- ❖ Inconsistent coal quality is a major concern for some CPPs
- ❖ Layout constraints can pose certain barriers in some facilities
- ❖ Air cooled condenser performance

### Policy

- ❖ Grid connectivity for increased PLF of CPPs is a major concern

### Financial

- ❖ Retrofit costs in some cases could be high
- ❖ Installation of storage and blending system for multi-fuel usage needs high capex, and has a longer payback period

## Technical paper no. 8: Increased Renewable Energy (RE) use in cement manufacture

### Current status

India today ranks among the world’s top five countries in terms of Renewable Energy (RE) capacity with around 20 GW installed base. This represents about 11% of India’s total power generation capacity (an increase from 3% – 11% in the last decade). Future targets are promising: Government of India (GoI) targets aim to achieve over 20% of the country’s total power generation in the next decade with an installed capacity of over 70,000 MW. GoI has also recently launched two unique and ambitious national missions; the National Solar Mission seeks to facilitate the generation of 20,000 MW of solar power by 2022, and the National Biomass Mission aims to tap bioenergy potential of over 25,000 MW.

A modern one MTPA capacity cement plant requires about 15 MW of installed capacity of electrical energy for its operation. The use of renewable energy up to 100% is site-specific and may be possible in some cases. Experience from one CSI member company shows that higher renewable energy rates can be achieved if older, smaller capacity wind turbines are replaced by new technology, higher capacity wind turbines, and solar PV systems can be erected on the same site, to gain from both wind and solar power in a single system.

The estimated potential and the area required to generate power for renewable energy technologies are given below:

No.	Technologies	Estimated potential (MW)	Tapped potential (MW)	Area required
1.	Wind power	48,561	14,989	20 – 25 acres/MW
2.	Biomass power	16,881	1,083	1 – 1.5 acres/MW
3.	Biomass cogeneration	5,000	1,779	0.75 – 1.2 acres/MW
4.	Waste to power	2,700	73	4 – 5 acres/MW
5.	Solar PV	20,000	17.82	5 acres/MW
6.	Solar thermal	35,000	unknown	7– 12 acres/MW
7.	Small hydro	15,385	3,105.63	unknown

### Options available

#### ❖ Wind power

Several cement plants have installed wind farms in many locations across the country. Wind power also has the advantage of wheeling (power transmission through national electricity grid) and banking (feeding power generated to the grid for use at a later time), thereby yielding higher benefits.



#### ❖ Biomass

Stand-alone biomass power generating units; the cost of biomass is increasing, making it expensive for power generation.

#### ❖ Waste to power

Technical and administrative issues mean waste to power is not suitable for installation at all plants, and a plant will need to carry out a good community engagement process for local acceptance.

#### ❖ Solar PV

One of the major reasons for very few solar PV installations is the price constraint and the requirement of large area. Cement plants can install these in a different location and can 'wheel' the power, or can install solar PVs in used mined areas, or for pumping, street lighting and air conditioning. The estimated cost of solar PV is around INR 140 million/MW (approximately USD 2.8 million), potentially dropping to around INR 70 million/MW (approximately USD 1.4 million) in the coming decade, making it easier to undertake large installations (the cost of coal based power generation today, for comparison, is about INR 45 million/MW) (approximately USD 900,000).

#### ❖ Solar thermal

Solar thermal can be used for hot water generation and chilling purposes (Vapor Absorption Machine or VAM). There is a good potential for solar thermal installation in cement plants.

#### ❖ Small hydro power generation

Several initiatives have been conducted to tap larger hydro plants, but few in small hydro plants, thereby yielding opportunity to venture more into this area.

### **Anticipated Benefits**

Thermal savings: nil

Electrical savings: 30% of electrical energy offset through RE use

CO<sub>2</sub> reduction: 24 kg CO<sub>2</sub>/tonne of cement (for 30% use of RE)

### **Primary influencing parameters**

- ❖ Availability of appropriate sites for RE installation (on-site/off-site)
- ❖ Cost of electrical power
- ❖ Government incentives/policies for increased RE utilization
- ❖ Innovative developments for integrating RE within the cement manufacturing process

## Cost estimation

No.	Technologies	Capital cost (INR million / MW)	Capital cost (approx. USD / MW*)	Typical Plant Load Factor (PLF) (%)
1.	Wind power	50 – 60	1 – 1.2 million	20 – 30
2.	Biomass power	30 – 45	600,000 – 900,000	70 – 75
3.	Bio-mass cogeneration	34 – 40	680,000 – 800,000	45 – 55
4.	Waste to power	30	600,000	75 – 80
5.	Solar PV	140	2.8 million	20 – 30
6.	Solar thermal	120	2.4 million	25 – 40
7.	Small hydro	40 – 50	800,000 – 1 million	19 – 40

\* USD 1 = INR 50

## Conditions, barriers and constraints

### Technical

- ❖ Sites of high wind energy potential have already been utilized; in some cases, with lower capacity wind turbines
- ❖ Raw material availability for continuous feeding of biomass is a major concern

### Policy

- ❖ Municipal Solid Waste (MSW) could be an excellent option for power from waste; but lack of enabling policies is a major deterrent
- ❖ Enabling policies for increased RE generation, such as attractive feed-in tariffs, wheeling and banking policy, etc are commendable in a few states, but these are not widespread across the whole country
- ❖ Absence of policy for offshore wind power generation
- ❖ Higher import duties and taxes increase initial investment requirements

### Financial

- ❖ Initial investment for several RE based power plants is very high, and often cannot meet the company's return on investment targets

## Technical paper no. 9: Energy efficiency improvement in electrical systems

### Current status

Some of the plants in the Indian cement industry are already equipped with the latest available technology in electrical systems, like intelligent Motor Control Centers (MCC) and Energy Management Systems (EMS); and so on. Such technologies can be replicated in other plants. These systems occupy a prominent role in control schemes, housing a comprehensive array of control and monitoring devices. MCCs have moved rapidly to include the latest component technologies, and integrating these advanced technologies presents a major opportunity – to transform islands of data into useful information that minimizes operational downtime. The equipment is mostly found to be loaded at around 50–70%; here voltage optimization can yield energy savings. Frequency optimization also holds strong potential if the plant is not synchronized with the grid and is running in ‘island mode’. Plants can go as low as 48Hz as the generating frequency. Lighting voltage generally observed in industry is on the higher side; but can be reduced to around 210–215 V without decreasing the lux levels too much.

### Technologies proposed

#### ❖ Energy Management System (EMS)

Measurement is vital in energy efficiency improvement activities. Energy management systems help in measuring all important parameters required for better energy management.

#### ❖ Use of EFF-1 (premium efficiency) motors

Motors are the major consumers of electrical energy in any industry. The use of high efficiency motors substantially reduces energy consumption as a whole. The use of energy efficient motors can be adopted in the design stage as well as a retrofit option.

#### ❖ Light Emitting Diode (LED) and magnetic induction lamps for lighting

The lighting system consumes nearly 5% of the total electrical energy consumption of a plant. The use of Light Emitting Diodes (LEDs) and magnetic induction lamps for illumination has become common practice in many industries. Both LEDs and magnetic induction lamps consume only one quarter of the energy consumed by other electrical light sources.

#### ❖ Maintaining near to unity power factor in CPP

In a synchronized system, i.e., when the CPP and grid are synchronized, the power factor of the CPP end is usually maintained at a lower level, so as to maintain a higher power factor at the grid end. This is done to decrease the reactive power consumption from the grid and avoid penalty. However, near to unity power factor can be maintained at both the ends by installing capacitor banks at the load end. Care should be taken to avoid a leading power factor in CPP in partial load or no load conditions to avoid damage to alternator.

#### ❖ Voltage optimization in motors and lightings

Any voltage supply above the motor rated voltage will result in higher voltage related losses. Therefore, it is advised to optimize the supply voltage to the motors. All the Low Temperature (LT) motors are rated for 415V only, and hence the desired terminal voltage of motors could be in the range of 400–415V with sufficient reactive power management. Similarly, for lighting circuits, the optimum voltage level is 208V for general lighting network. It is highly recommended to have a separate transformer for lighting with fine voltage control if possible.

#### ❖ Frequency mode optimization

In the case of a CPP operating in an island mode, an opportunity exists to optimize energy consumption of the connected load by reducing the supply frequency. Since the power consumption of centrifugal equipment varies with speed, any reduction in input frequency results in reduced speed, thereby reducing the power consumption.

#### **Anticipated benefits**

Thermal savings: nil

Electrical savings: 1 – 3 kWh/mt cement

CO<sub>2</sub> reduction: 1.5 – 4 kg CO<sub>2</sub>/mt cement

#### **Primary influencing parameters**

- ❖ Present level of energy efficiency and specific energy consumption
- ❖ Current levels of technology adoption
- ❖ Cost of electrical power

#### **Cost estimation**

Investment costs depend on extent of absorption of energy efficient technologies and hence, overall cost estimation is not ascertained.

#### **Conditions, barriers and constraints**

Technical

- ❖ None to date

Policy

- ❖ None to date

Financial

- ❖ Prolonged return on investment is long for few projects, such as change to LED lighting or installation of high efficiency motors

## Technical paper no. 10: Utilization of advanced automation systems in cement manufacture

### Current status

An effective advanced automation and control system can bring substantial improvements in overall performance of the kiln, increased material throughput, better heat recovery and reliable control of free lime content in clinker. Furthering the scope of automation in process control, quality is also maintained by continuous monitoring of the raw mix composition with the help of x-ray analyzer and automatic proportioning of raw mix components. New types of on-line bulk material analyzers have also been developed based on Prompt-Gamma-ray Neutron Activation Analysis (PGNAA) to give maximum control over the raw mix. The analyzer quickly and reliably analyzes the entire flow online providing real time results. The latest trends in online quality control include computers and industrial robots for complete elemental analysis by x-ray fluorescence, x-ray diffraction techniques, online free lime detection, and particle size analysis by latest instrumental methods.

A few other mine management measures could be installation of mobile crushers for productivity improvement and radio controlled mines machinery monitoring system for better control and optimization

The control and operation of kiln systems today is extremely complex, with properties of input fuel and feed materials varying greatly and with product standards becoming increasingly stringent. Cement kiln operators today encounter such sudden variations that dynamic control of the kiln is vital to achieve optimum results and lower manufacturing costs.

Some of the proven control systems employed for optimal performance and quality are:

- ❖ Adaptive predictive control system
- ❖ Online shell scanner and refractory management
- ❖ Online NOx control
- ❖ Online flame control
- ❖ Online free lime control
- ❖ Flow measurement with advanced techniques
- ❖ Online measurement of kiln health
- ❖ Online Energy Management System (EMS) for drives and power generation
- ❖ Remote monitoring and operation for split location plants

Grinding systems are also undergoing significant improvements, more from their operation as the grinding technology has been witnessing only incremental improvements over the last several years. Automation and control systems can significantly improve the performance of grinding systems by reducing the variations, maintaining precise particle size distribution and increasing throughput.

The adaptive predictive control system works based on soft sensors input, and the prediction mechanism works on set parameters. The operation of the system is predicted and corrective action is taken. If the corrective mechanism is not as per the requirement (or set value), the mechanism automatically refines itself. The system constantly upgrades itself to meet the system fluctuations and keeps improving with time.

## Anticipated benefits

Thermal savings: 6 – 8 kcal/kg clinker

Electrical savings: 3 – 6 kWh/mt clinker

CO<sub>2</sub> reduction: 4 – 8 kg CO<sub>2</sub>/mt cement

## Primary influencing parameters

- ❖ Expert control systems simulate the best operator by using information, hence the expertise level of operators is vital
- ❖ Present levels of operation efficiency and energy efficiency
- ❖ Existing plant configuration determines additional equipment requirement
- ❖ Uptime of control systems could be a concern

## Cost estimation

- ❖ Cost of control system per kiln varies from INR 4 million to 5 million (approximately USD 80,000 – 100,000)

## Conditions, barriers and constraints

### Technical

- ❖ Uptime of control system is a concern. Typical uptime varies from 70---80%, thereby affecting kiln control, energy efficiency and overall return on investment

### Policy

- ❖ None to date

### Financial

- ❖ Return on investment could be long (about 4-6 years) in a few cases (with low energy tariff)

## Technical paper no. 11: Increasing Thermal Substitution Rate (TSR) in Indian cement plants to 30%

### Current status

Alternative fuel use in the Indian cement industry is at very low levels; the country's average stands at less than 1% of Thermal Substitution Rate (TSR). Several nations globally have utilized cement kilns as an effective option for their country's industrial, municipal and hazardous waste disposal. This creates a win-win situation for both the local administration and the cement plants: the administration utilizes the infrastructure already available at cement kilns, thereby spending less on waste management, and the cement kilns are paid by the polluter for safe waste disposal, as well as having their fuel requirements partly met.

Various studies indicate that the Greenhouse Gas (GHG) emissions reduction potential through waste utilization in cement kilns is extremely high. International experiences highlight extensive opportunities for such Alternative Fuel and Raw Materials (AFR) usage, for example the Japanese cement industry utilizes over 450kg of waste per tonne of cement manufactured, and European cement plants have a TSR average of about 40%. If the TSR in the Indian cement industry could increase to 30% by, for example, 2030, GHG emissions could reduce substantially; to such an extent that it could make a difference in the overall country's emissions. The typical types of wastes being used as alternative fuels are industrial wastes (automotive, pharmaceutical and engineering industry wastes being the most common) and biomass-based fuels.

The GHG emissions reduction opportunity through increased TSR is basically on two fronts: first, biomass-based alternative fuels are considered carbon neutral (as its subsequent growth fixes the carbon emitted during its combustion), and second, the use of other alternative fuels reduces the use of primary fossil fuel (coal, petroleum coke, and so on). These alternative fuels would have otherwise resulted in equivalent emissions, if other modes of disposal, such as incinerators or land-filling are chosen instead of cement kilns. Both biomass-based and other alternative fuel types must be considered in the Indian scenario: an agrarian economy like India offers several biomass-based alternative fuels and the use of other alternative fuels in cement kilns reduces the need of local governments for separate installations for waste disposal, such as landfill sites or expensive incinerator facilities.

Cement kilns can, theoretically, operate with 100% TSR, thereby completely off-setting the need for primary fossil fuels. However, several other enabling factors, such as the installation of adequate pre-processing and blending facilities, and the availability of alternative fuels without technical limitations (heat content, larger proportion of detrimental trace elements, chlorine, sulfur and so on ) have to be considered.

Cement kilns can exhibit significantly varying behaviour depending on the type of alternative fuel substituted, and hence the technical competence of the industry should be adequate to face these challenges which come alongside a TSR increase. With extensive national and global expertise available, the Indian cement industry today is technically ready for adopting higher TSR rates.

Increased TSR in the cement industry would be possible if the waste legislation in the country progresses in line with the industry's increased need for alternative fuels. First and foremost, a change in perspective amongst policy makers is required, to explore cement kiln utilization of waste disposal. Secondly, stringent waste legislation is needed, which enables high heat content waste to be co-processed in cement kilns rather than in incinerators, wherein the heat content goes largely unutilized. It is important that the legislation related to cement kilns is as stringent as for dedicated waste facilities. Thirdly, to ensure availability and consistency of alternative fuel quantity and quality, waste legislation in the country should enable effective waste collection, treatment and processing; by a new service industry sector which works as an effective intermediary between waste generators and the cement industry. The pricing of waste is also a key factor, both to ensure waste minimization at source (to

reduce disposal costs for waste generators) as well as to ensure zero or negative cost to cement manufacturers (encouraging them to install the expensive handling, storage and firing facilities at their premises) for increased TSR. The fifth key factor is the social acceptance of using wastes as alternative fuels in cement kilns, both in the society in which the cement kiln operates, as well as among the cement user community.

India's Municipal Solid Waste (MSW) management is also a matter of growing concern. The country's urban population grew from 290 million reported in the 2001 census to an estimated 340 million in 2008, and is projected to reach 590 million by 2030 (McKinsey Global Institute, 2010). While India's urban population grew by 230 million in about 40 years (from 1971 to 2008), the next 20 years is expected to bring a 250 million surge. This emphasizes the rapid urbanization in India at an unprecedented rate. Such increasing urbanization rates would create higher demand for MSW management, considering increasing income levels and evolving lifestyle choices. Therefore, effective waste management practices become imperative for the sustainable growth of the country. The Prime Minister's National Action Plan on Climate Change – National Mission on Sustainable Habitat – has also identified urban waste management as a major component for ecologically sustainable economic development.

India's industrial waste is also growing in volume: recent estimates indicate that around 6.2 million tonnes of hazardous waste is generated annually, of which around 3.09 million tonnes is recyclable, 0.41 million tonnes can be incinerated and 2.73 million tonnes can go into landfill. Considering such significant hazardous waste generation, local administration, civic bodies and policy makers face challenges of effective and safe disposal.

There is, therefore, an urgent need to implement appropriate policies and practices in favor of co-processing in India, which can contribute towards the country's waste management needs. It will also help industry to achieve reasonable TSR in the cement manufacturing process.

To do this, the cement industry faces two-pronged challenges: first, technical competence for handling increased alternative fuels needs to be built in the industry, and second, there is a lack of enabling waste legislation that fosters higher TSR. With such enabling legislation, certain cement kilns in India have exhibited peak TSR of up to 12%. By virtue of adequate technical capability and enabling policies, the Indian cement industry can target 30% TSR in the years ahead.

### **Anticipated benefits (for thermal substitution rate of 30%)**

Thermal savings:	0 - 40 kcal/kg clinker (increase)
Electrical savings:	0 - 3 kWh/tonne of clinker (increase)
CO <sub>2</sub> reduction (PPC):	70 - 150 kg CO <sub>2</sub> /tonne of cement (net reduction)
CO <sub>2</sub> reduction (PSC):	70 - 210 kg CO <sub>2</sub> /tonne of cement (net reduction)

**The Indian cement industry has limited experience of increased use of alternative fuel in its cement kilns. Wherever alternative fuel has been used in Indian cement kilns (up to 10-12% TSR), alternate fuel is largely dominated by use of biomass. No / very marginal increase in energy consumption is observed in such kilns at this TSR levels.**

**For target TSR levels of 30%, given the lack of experience in Indian kilns, increase in thermal energy consumption of 0-40 kcal/kg clinker is based only on international experiences at increased alternative fuel usage levels.**



## Primary influencing parameters

- ❖ Availability of alternative fuels
- ❖ Fuel properties, suitability for utilization in cement kilns
- ❖ Maximum possible substitution rates
- ❖ Negative effect on kiln throughput, electrical and thermal energy consumption
- ❖ Ease of regulatory procedures

## Cost estimation

- ❖ Investment cost for increased alternative fuel use would largely depend on the type of fuel / raw materials used and the TSR. While certain alternative fuels, such as biomass can be relatively inexpensive to use, others may require expensive processing before it could be used in kiln. Considering the diversity of alternative fuels currently available and a TSR of 10% over next 5-10 years, the cost is estimated to vary between INR 5 to 20 million (approximately USD 100,000 – 400,000).

## Conditions, barriers and constraints

### Technical

- ❖ Effect of increased TSR on kiln production and specific energy consumption
- ❖ Complete understanding of impacts of minor constituents on long-term cement performance

### Policy

- ❖ Lack of waste legislation encouraging co-processing in the cement industry
- ❖ Non-existence of structured waste processing industry
- ❖ Lack of source segregation, collection, handling and logistics of MSW
- ❖ Lack of policy guidelines on the cost of alternative fuels (negative, nil or positive cost)
- ❖ Complicated procedural system for co-processing (permits, test runs, inter-state waste transportation challenges among others )
- ❖ Importance in consistency between legislation for cement kilns and for dedicated waste facilities

### Financial

- ❖ Higher investment and operating costs of waste pre-processing facility
- ❖ No established pattern to evaluate the cost of alternative fuel (negative, nil or positive cost)

## **Impacts of increased use of alternative fuels and raw materials in the cement manufacturing process**

### **Introduction**

The potential benefits of co-processing alternative fuels and raw materials in cement manufacture, when carried out in a safe and environmentally sound manner, are numerous. However, poor planning or inadequate preparations, or using alternative fuels and raw materials without understanding their potential or properties, may result in, for instance, a decrease in productivity, or increased emissions of basic and hazardous pollutants.

The most direct benefit is the harnessing of the energy contained within alternative fuels and materials as this replaces demand for fossil fuels like coal and also avoids depletion of deposits of new raw material sources such as limestone, bauxite and others. Thus, co-processing these alternatives shall reduce fossil fuel dependency and contribute to resource conservation.

As alternative fuels may have lower carbon contents, on an energy basis, than fossil fuels, another direct benefit is a potential reduction in CO<sub>2</sub> emissions at plant level. In addition, there are cost savings from the use of pre-existing kiln infrastructure to co-process waste that cannot be otherwise minimized, reused or recycled, without the need to invest in purpose-built incinerators or landfill facilities.

Regardless of the above benefits, alternative fuels and raw materials should only be used in facilities that employ the highest environmental practices and best available techniques. It should be ensured that the installed plant equipment can handle the alternative fuels well and burn them fully. Furthermore, stringent quality controls for cement products and the nature of the manufacturing process means that only carefully selected waste with recoverable calorific or material value are suitable for use as alternative fuels or alternative raw materials. All such materials must meet strict specifications before use.

Several factors must be taken into consideration when deciding on the suitability of the waste materials, including potential impacts on the health and safety of workers and the public, plant emissions, existing operations and final product performance. Commonly restricted wastes include, among others, infectious medical waste; scrap electronics metal; explosives, and waste of unknown or unpredictable composition including unsorted municipal waste. Ultimately, however, it will be the local raw material and fuel chemistry, the infrastructure and the cement production process, the availability of equipment for controlling, handling and feeding the waste materials, and site specific health, safety and environmental issues, which will determine the waste categories to be accepted at specific facilities.

### **Effects of minor chemical constituents on cement manufacturing**

Many of the components in conventional raw materials and fuels such as metals, halogens, and organic compounds, are identical to the components found in wastes used as alternative fuels and raw materials. For instance, chlorine can be found in raw materials such as clay and limestone, and in both conventional (coal) and alternative fuels (waste derived fuels). Alkalis (most commonly, Na<sub>2</sub>O and K<sub>2</sub>O) are typically found in the raw materials (clay or shale), but they can also be found in alternative raw materials such as fly ash and blast furnace slag. Sulphur is found in both raw materials and fuels (respective examples of each include limestone and coal), and heavy metals are ubiquitous in all cement kiln input materials.

Thus, cement manufacture requires that an adequate quality control system be strictly adhered to for all the materials used, whether conventional or alternative. Some variables that should be considered when selecting waste materials include those described below.

### **(a) Effects on kiln operation:**

Alkalis, sulphur and/or chlorides:

Excessive inputs of alkalis, sulphur and/or chlorides may lead to build-up and blockages in the kiln system. Where these cannot be absorbed in the cement clinker or kiln dust, a gas bypass may be required to remove excess alkali, chloride and sulphur compounds from preheater/precalciner kiln systems. High alkali content may also limit recycling of kiln dust back into the system.

A bypass system is not typically required unless the chloride content of the raw mix exceeds 0.015%. Because a chlorine bypass system will also result in additional energy demands (for instance, a bypass of 1% kiln gas will increase the specific heat consumption by 1.75-2.4 kcal/kg clinker), its use is best avoided by controlling chloride inputs.

### **(b) Effects on emissions:**

#### **Chlorides:**

Chlorides may combine with alkalis to form fine, difficult to control particulate matter. In some cases, chlorides have combined with ammonia present in the limestone feed. This produces highly visible detached plumes of fine particulate with high ammonium chloride content. Although emissions of HCL can result if inputs exceed the capacity of the clinker to absorb inbound chlorine, there is limited evidence that HCL emissions may be independent of chlorine input to a kiln system, possibly due to the affinity of chlorine for calcium and alkali metals.

#### **Heavy metals:**

The non-volatile behaviour of most heavy metals allows most to pass straight through the kiln system and be incorporated into the clinker, or be controlled through use of standard air pollution control devices. However, volatile metals will partly be recycled internally by evaporation and condensation until equilibrium is reached, the other part being emitted in the exhaust gas. Thallium, mercury and their compounds are highly volatile as to a lesser extent are cadmium, lead, selenium and their compounds. The fact that dust control devices can only capture the particle-bound fraction of heavy metals and their compounds needs to be taken into account. Mercury is a highly volatile metal, which, depending on the exhaust gas temperature is present in both particle-borne and vapour forms in the air pollution control equipment. Inputs of wastes containing or contaminated with mercury to the kiln should be avoided and kept to a minimum.

#### **Sulphur:**

The oxidation of sulphide or elemental sulphur contained in the fuel during combustion results in SO<sub>2</sub>. In addition, sulphide or elemental sulphur contained in raw materials may be 'roasted' or oxidized to SO<sub>2</sub> in areas of the kiln system where sufficient oxygen is present and the material temperature is in the range of 300-600°C. Sulphates in the raw mix can also be converted to SO<sub>2</sub> through localized reducing conditions in the kiln system. Although high sulphur inputs may result in the release of SO<sub>2</sub>, the alkaline nature of the cement provides for direct absorption of SO<sub>2</sub> into the product, thereby mitigating the quantity of SO<sub>2</sub> emissions in the exhaust stream.

## **Dioxins and furans (PCDD/PCDF):**

PCDD/PCDF or advanced precursors that might be present in conventional raw materials (rarely) or wastes used as alternative raw materials, are partially roasted off at material preheating. PCDD/PCDF can be formed by the 'de novo synthesis mechanism' in or after the preheater and in the air pollution control device if chlorine and hydrocarbon precursors are available in sufficient quantities in the temperature range 200° C to 450° C. This notwithstanding, research has shown that most cement kilns can meet an emission level of 0.1 ng TEQ/Nm<sup>3</sup> if primary measures are applied, and that co-processing of waste fed to the main burner, kiln inlet or the precalciner does not seem to influence or change the emissions of persistent organic pollutants.

### **(c) Effects on clinker, cement and final product quality:**

**Phosphate:** High levels of phosphate may slow setting time.

**Fluorine:** High levels of fluorine will affect setting time and strength development. Controlled levels of fluorine (0.2–0.3%) on clinker basis, due to the mineralizing effect could facilitate the following: improved burnability of kiln feed; increased C<sub>3</sub>S formation; improved clinker granulation and ease of grindability of clinker; increased cement mill performance; and improved cement quality.

### **Chlorine, sulphur and alkali:**

High levels may affect overall product quality. High chlorine content increases the corrosion of reinforcement in concrete.

### **Heavy metals:**

Thallium and chromium content can adversely affect cement quality and may cause allergic reactions in sensitive users. Although leaching of chromium from concrete debris may be more prevalent than leaching of other metals, research has shown that the main sources of chromium in cement come from raw materials, refractory bricks in the kiln and chromium steel grinders, and that both conventional and alternative fuels constitute only minor sources. Limestone, sand and, in particular, clay contain chromium, making its content in cement not only unavoidable but also highly variable. Some industrial wastes have high a chromium content which limits co-processing.

While organic pollutants in the materials fed to the high temperature zone of the kiln system are nearly completely destroyed, the inorganic components partition between the clinker product and kiln dust. Accordingly, the use of wastes in the clinker burning process may change the metal concentrations in cement products, and depending on the total input via the raw materials and fuels, the concentration of individual elements in the product may increase or decrease as a result of waste co-processing. However, lengthy investigations have shown that the effect of waste on the heavy metals content of clinker is marginal on a statistical basis, the one exception being the bulk use of tires which will raise zinc levels. Small amounts of zinc (0.01–0.2%) have been found to increase the reactivity of C<sub>3</sub>A<sub>6</sub> and in consequence lead to possible setting time problems. However, the presence of up to 0.5% of ZnO does not appear to have a profound effect on other hydraulic properties.

As cement is blended with aggregates to form concrete or mortar, it is the behaviour of the metals within these building materials that is important for the evaluation of relevant environmental impacts of waste used in the production process. Studies have shown that metal emissions from concrete and mortar are low, and comprehensive tests have confirmed that metals are firmly incorporated in the cement brick matrix. Moreover, storage under different and partly extreme conditions has not led to any environmentally relevant releases, which also holds true when the sample material is crushed or comminuted prior to the leaching tests.

In regard to the above, the main results of leaching studies done to assess the environmental impacts of heavy metals embedded in concrete have shown that no significant differences in leaching behaviour of trace elements have been observed between different types of cements produced with or without alternative fuels and raw materials. However, leached concentrations of some elements, such as chromium, may, under certain test conditions, come close to limits given in drinking water standards; hexavalent chromium in cement is water-soluble and may be leached from concrete at a level higher than other metals, so chromium inputs to cement and concrete should be as limited as possible.

## Technical paper no. 12: Opportunities for exploring development of energy plantation by the cement industry

### Current status

Meeting energy demands of the cement industry through energy plantations is a promising futuristic enterprise. Energy plantation comprises growing select species of trees and shrubs, which can be harvested in short cycles (3–6 years only for each cycle) for two potential next steps: first, wherein plantation grown is harvested and utilized in kilns as an energy source, and secondly, wherein plantation grown is harvested and used as biodiesel, methanol, ethanol etc for a variety of other applications.

The use of biomass crops to produce fuels has many advantages: non-food crop of a renewable nature, reduced Greenhouse Gas (GHG) emissions, nutrient recyclability (lower inputs required), longer growing season (more carbon fixed) in some cases, and so on. Compared to fossil fuel, most biofuels are environmentally benign with the emission of very little sulfur and non-toxic chemicals. However, the development of biofuels from lignocellulosic biomass is a major step toward harnessing one of the world's most prevalent, yet least utilized renewable energy resources.

In India, the interest in biofuels has grown substantially during the last few years. The primary reason for this is that energy security, better environmental performance, greening of wastelands, and creation of new employment opportunities are seen as some of the advantages of biofuels. Biofuels may be considered, and accordingly developed, as a multi-dimensional beneficial energy alternative for our nation. The two biofuel types currently in focus in India are (i) bioethanol and (ii) biodiesel.

#### Bioethanol from molasses

Molasses, a by-product of sugar manufacture, is currently the most widely used feedstock for ethanol production in India. The sugar present in molasses is fermentable and can be used to produce bioethanol.

#### ❖ Bioethanol from sweet sorghum

Of late, bioethanol production from sweet sorghum has demonstrated significant potential. Sweet sorghum, a crop with wider adaptation, grows rapidly and results in higher biomass production. It has a four month crop cycle, which results in two crops annually, compared to only one in the case of sugar cane.

#### ❖ Bioethanol from cellulosic biomass

Hydrolysis is a technology used for bioethanol production from cellulosic biomass. The technology, still in its infancy, seems promising in the Indian scenario, thanks to the excess availability of cellulosic biomass feedstock in the country. It is estimated that there is a favourable energy and carbon balance for bioethanol from the two most widely available biomass residues in the country, i.e., bagasse and rice straw. The steps involved in manufacturing bioethanol from both these feedstocks are similar, but the difference in yield of bioethanol and the co-products result in some difference in the final results obtained.

#### ❖ Straight Vegetable Oil (SVO) from jatropha

Jatropha has been discussed as one of the key sources of biofuels in India. With extensive jatropha plantations being initiated across the country, it may play a major role in shaping the future of the Indian biofuel sector. SVO from jatropha can be used directly as a fossil diesel substitute in simple engines. It is also one of the more economical fuels, for decentralized use, especially in rural Indian areas.

❖ Biodiesel from jatropha

To overcome the shortcomings of SVO, it can be further treated and processed for biodiesel production. The most widely used technology to convert oil to biodiesel is called transesterification. This fuel can be used in diesel engines without any alteration and can also be blended with petro-diesel for end use.

Biofuel type	Feedstock	Net energy ratio	Net energy balance (GJ / kl)	Net carbon balance (tCO <sub>2</sub> e / kl)	% carbon emission reduction
Bioethanol	Molasses	4.57	19.11	- 1.1	75
	Sweet sorghum	7.06	21.57	-1.4	86
	Cellulosic biomass (Bagasse)	4.39	25.41	-1.7	70
	Cellulosic Bio-mass (Rice straw)	3.32	22.79	-1.6	68
Biodiesel	Jatropha -transesterification	3.41	63.76	- 4.0	30
	Jatropha- SVO	4.38	66.73	-4.5	50

- ❖ **Net energy balance:** The energy supplied by the biofuel and associated co-products for end use minus the energy required during various manufacturing stages of biofuel
- ❖ **Net carbon balance:** The net quantity of greenhouse gas emitted/avoided to the atmosphere during the various stages of manufacture, distribution and end use of fuel.
- ❖ **Net energy ratio:** The ratio of energy output obtained from the end use of the biofuel and energy input used for the production of the biofuel.
- ❖ **% carbon emission reduction:** The net quantity of greenhouse gas emissions avoided compared to the use of the petro fuel substituted by the biofuel.

All the biofuels compared demonstrate a favorable energy balance, with the net energy ratio being >1 (i.e., the total energy output is greater than total energy input). The comparison also indicates the estimated negative carbon emissions, i.e., the biofuels significantly help reduce net carbon emissions into the atmosphere.

While, traditionally, energy plantation is used as biomass, biofuels also indicate promising results for cement industry to pursue. Over the next three to four decades, if the cement industry, in its pursuit for low-carbon growth can replace 5% of its fossil fuel sources with biofuels, it will significantly offset carbon emissions.

**Anticipated benefits (for 5% replacement of fossil fuel by biofuel)**

Thermal substitution: 30 – 45 kcal/kg clinker

Electrical savings: nil

CO<sub>2</sub> reduction: 5 – 10 kg CO<sub>2</sub> / tonne of cement

## **Primary influencing parameters**

- ❖ Large land area requirement
- ❖ Highly labor intensive
- ❖ Conversion to biofuel from biomass is capital intensive
- ❖ Requirement of further research to increase scale of operations and reduce overall cost

## **Cost estimation**

- ❖ This is still an emerging area of focus and cost estimates for land, cultivation, harvesting, transportation and conversion to biofuel, and cost for end-users will be site-specific

## **Conditions, barriers and constraints**

### Technical

- ❖ Efficiency and scale of biomass conversion to biofuel is still very low
- ❖ Skills and expertise in this area are not widespread
- ❖ Crops are dependent on the suitability of weather and other resources

### Policy

- ❖ Lack of adequate policy incentives for industrial sectors to promote bioenergy plantations and biofuel utilization. Presently, biomass cultivation is only allowed on dry and arid lands
- ❖ Guidelines on land availability, utilization and local community development yet to be evolved

### Financial

- ❖ The present biofuel cost is higher than for fossil fuels. Financial incentives are required to promote biofuels



## Technology paper no. 13: Reducing clinker factor in fly ash based Portland Pozzolona Cement (PPC)

### Current status

The increased use of fly ash in Portland Pozzolona Cement (PPC) directly impacts the reduction of clinker factor in cement (clinker factor: % of clinker content by cement mass), thereby reducing CO<sub>2</sub> emissions through reduced fuel combustion and reduced limestone calcination. Therefore, exploring newer technical avenues for maximizing the utilization levels of fly ash represents a big challenge and opportunity for CO<sub>2</sub> reduction.

In India, the estimated generation of fly ash is of the order of 190 million tonnes in 2010-11, expected to reach 450 million tonnes by 2020-21, and 900 million tonnes by 2031-32 (Source: Department of Science and Technology, Government of India). At present, about 100 million tonnes of fly ash is being utilized in cement and other building materials. Indian standard specification IS: 3812 (part 1) 2003 exists for quality of fly ash to be used as pozzolona, and IS: 3812 (part 2) 2003 relates to the quality of burnt clay that can be used as pozzolona. The American Society for Testing and Materials (ASTM) and European (EN) standards for quality of fly ash are C-618-08 and ENV: 197-1-1992, respectively. While fly ash is abundant in India and is widely used, burnt clay pozzolona is not so popular. Besides its use as pozzolanic additions in the manufacture of PPC, fly ash is used in many other areas, such as a raw material component for the manufacture of Ordinary Portland Cement (OPC), sintered fly ash lightweight aggregates and concrete, cement/silicate-bonded fly ash/clay fly ash building bricks, pre-cast fly ash concrete building units, cellular concrete, bricks and blocks, lime and cement fly ash concrete, structural fill for roads, construction sites, land reclamation and so on, as a filler in mines, as a filler in bituminous concrete and manufacture of insulating and semi- insulating bricks, as a plastisizer and a pumping aid, as a water reducer in concrete and sulphate resistant concrete and as a filler in paints and pigments and so on. Fly ash use as pozzolona in PPC, however, remains the biggest user segment. PPC production reached 102.3 million tonnes during 2010-11, which amounted to 60.79% of total cement production in India.

Fly ash conforming to standard IS: 3812 (1) 2003 can be used (up to 35% maximum) in the manufacture of PPC as per IS: 1489 (part 1) 1991. The role of fly ash in PPC is attributed to the pozzolanic action leading to a contribution to strength development. Studies carried out on the Indian fly ash samples have indicated that the range of glass content varies between 15 and 45% and the Lime Reactivity (LR) between 2.0 and 7.0 mpa. The fine fraction of fly ash below 45 micron is a major portion, and contributes predominantly to the performance of PPC. This particular aspect of fly ash is very important with a view to enhance the % of use of fly ash in PPC and concrete and needs further thorough and systematic investigations to arrive at adoptable methodologies of using finer fly ash at higher levels. The quality of the clinker and suitable and adequate admixture addition will improve the fly ash absorption. The addition of plasticizers will help in fly ash absorption in concrete applications.

Studies have been undertaken with a view to enhancing lime reactivity of dump ash / pond ash, and fly ash from initial fields of Electrostatic Precipitator (ESP) so that non-conforming fly ash could be made reactive and conform to IS: 3812 (1) 2003 and could gainfully be utilized. These studies have revealed that such fly ash could be utilized up to an average of 25% after activation through mechanical (by screening, fine grinding and separation), chemical (froth flotation, washing with acid and alkalis, and filtration), and thermal (sintering) and electromagnetic routes. The studies on activation of conforming fly ash also indicate that fly ash utilization levels could be increased by about 10-15% from the current levels, subject to revision of national standards.

The European standard (EN-197) for Pozollanic cement type IV/B and South African standard SANS 50197 for Pozollanic cement type CEM IV B allow addition of siliceous fly ash in the range of 36-55 % which are more than the limit of 35 % fly ash addition as per Indian standard IS: 1489 (part 1) 1991.

## Anticipated benefits

Thermal savings: saving potential: 180 - 235 kcal /kg cement PPC (27 - 35% fly ash replacement)

Electrical savings: saving potential: 13 - 17 kWh/t PPC.

*Note: The above figures have been arrived at considering the power saving from substitution of clinker by fly ash (27-35%) with grinding in a close circuit ball mill.*

CO<sub>2</sub> reduction (direct): 220-280 kg CO<sub>2</sub>/t PPC (for cement with 27 - 35% by mass fly ash).

CO<sub>2</sub> reduction (indirect): 1kWh in specific power consumption reduces CO<sub>2</sub> emission by 1kg hence, reduction in CO<sub>2</sub> emission is expected to be 13 - 17kg/t PPC (for cement with 27 - 35% by mass fly ash).

*Note: The above thermal/electrical savings are calculated considering OPC (95% clinker) as the base level, 27% fly ash or current national average in PPC, and 35% fly ash as the achievable target in future.*

## Primary influencing parameters

The permitted level of fly ash in India is 15-35% as compared to European standards (6-55%) by weight for siliceous fly ash (source: European Cement Research Academy (ECRA)). Several technical reasons contribute to lower utilization of fly ash in India:

Poor quality of Indian fly ash in terms of

- ❖ Low lime reactivity
- ❖ Low glass content
- ❖ High carbon content
- ❖ Varying fineness levels
- ❖ Exploitation of pozzolanicity of fly ash only, in cement and concrete use
- ❖ Fine powder effect is limited up to 5% in OPC (performance improver)

## Cost estimation

Investment cost depends on silo size at power plant complex, fleet size of tankers, type of handling equipment at plant and so on. The current estimated cost of fly ash collection systems at thermal power plant, handling and transportation to cement plant in mill hopper etc is in the range of INR 140-150 million (approximately USD 2.8 - 3 million) for indigenous supplies.

## Condition, barriers and constraints

Utilization of fly ash in cement, concrete and building materials largely depends on factors such as availability of the fly ash in dry state, and extent of variation in the quality of fly ash.

### Technical

- ❖ Provision of transportation of dry fly ash in closed wagons to prevent high transit losses and fugitive emissions as it is a fine powder.
- ❖ As the bulk of fly ash is disposed of in a wet state, arrangements have to be made for extraction and supply of fly ash in a dry state. Some plants have installed fly ash dryers to process wet fly ash, at huge capex (capital expenditure)
- ❖ Provision of marketing of standard quality fly ash in bags or any other packing such as drums, etc
- ❖ Variation in the quality of fly ash is one of the major problems related to its bulk utilization. Efficient coal blending systems and controlled coal combustion techniques will ensure good quality fly ash generation in Indian thermal power plants. Further research is required concerning the activation of non-conforming fly ash for their rational use

### Policy

- ❖ Need for modifications of existing standards and codes consequent upon the acceptance of different uses of fly ash and formulation of new standards whenever necessary
- ❖ Lack of consumer awareness on the quality of fly ash based products along with lack of confidence of builders in using fly ash

### Financial

- ❖ Tax relief and fly ash utilization subsidy will go a long way to promote increased utilization
- ❖ Limitation in distance over which fly ash can be commercially transported
- ❖ Long distance transportation of fly ash must be made economically viable through fiscal incentives

## Technology paper no. 14: Reducing clinker factor in slag based Portland Slag Cement (PSC)

### Current status

The increased use of Ground Blast Furnace Slag (GBFS) in the manufacture of Portland Slag Cement (PSC) has a direct impact on reducing the CO<sub>2</sub> emissions, by decreasing specific fuel consumption and reducing limestone calcination. Blast Furnace Slag (BFS) is obtained as a by-product in the manufacture of pig iron in the blast furnace of a steel plant. This slag has latent hydraulic properties and the ability to reduce heat evolution during cement hydration and therefore has a significant potential to replace clinker in cement in the manufacture of PSC.

India is currently the 4th largest producer of crude steel in the world. In 2003, it was the 8th largest producer and, considering ongoing expansion plans and capacity additions currently being undertaken by steel plants, it is expected that India will become 2nd largest producer of crude steel in the world by 2015. Crude steel production grew 8% annually (compounded annual growth rate) from 2005-06 to 2010-11 – detail is shown here:

	2005-06	2010-11
Per capita steel consumption (kg)	38	55
Capacity of crude steel production (mtpa)	51.17	78
Crude steel production (mtpa)	46.46	60.57
Production of finished steel (mtpa)	46.57	60.01

Usually, with every tonne of hot metal produced, approximately 0.45-0.50 tonne of granulated blast furnace slag (GBFS) is generated which poses environmental and land use concerns. The production of hot metal in the year 2010-11 was around 43 million tonne (annual report 2010-11, Ministry of Steel (Gol)). At present, the steel industry is able to granulate about 10 million tonnes of usable GBSF out of an approximate 22 million tonnes of (GBFS) generated in total. Considering a conservative growth rate of 8% for the steel sector (Ernst and Young estimate 9%), the estimated generation of (GBFS) will be around 43.9 mtpa in 2020 and about 95 mtpa in 2030. At present, an average of 40% (by weight) of GBFS is used in PSC in India.

The quality and performance of PSC is governed by the Indian standard specification IS:455-1989, which allows use of GBFS in the range of 25-70% (4th amendments). Considering the potential of a higher percentage use of GBFS in the manufacture of PSC, the steel industry could work to ensure 100% granulation of blast furnace slag generated in India. This will not only make the complete blast furnace slag usable in PSC manufacture but would also reduce the equivalent amount of clinker content in the cement manufacture (thereby reducing the clinker factor in PSC), as well as clearing large tracts of usable land which are otherwise occupied by un-granulated slag.

The European standard (EN-197) for blast furnace slag cement type III/B and III/C allows addition of ground GBFS in the range of 66-80% and 81-95% respectively, and similar limits are followed in South African standards SANS 50197 for blast furnace slag cement type CEM III B and CEM III C which are more than the limit of 70 % GBFS addition as per Indian standard IS: 455.

Indian standard specification IS: 12089-1987 for quality of GBFS is used in the manufacture of PSC. The quality of GBFS is governed primarily by its glass content, which should not be less than 85% as determined by an optical microscope. The chemical constituents, such as manganese oxide, magnesium oxide and sulfide sulfur, should not be more than 5.5, 17.0 and 2.0%, respectively. For good quality GBFS, proper granulation of the molten slag coming out of the blast furnace is necessary, to ensure the highest possible glass content. The quality of GBFS also greatly depends upon its fineness; the finer GBFS show a greater hydraulic behavior.

PSC is produced by inter-grinding GBFS, clinker and gypsum and permitted additives, or by intimately and uniformly blending Portland cement with ground GBFS. The compressive strengths of PSC at 3, 7 and 28 days should not be less than 16, 22 and 33 mpa as per IS:455. PSC production levels reached over 10 million tonnes during 2010-11 amounting to over 6% of total Indian cement production. Such replacement with clinker reduces the specific CO<sub>2</sub> emissions due to reduced calcinations of limestone and reduced thermal energy required for clinkerization per tonne of PSC.

There are many advantages associated with the use of GBFS in cement. GBFS undergoes hydration for a longer period, which enhances the long-term strength after 28 days (although there is a dip in strength at early ages). GBFS containing cement has higher chlorine-blocking characteristics than OPC and is therefore an effective way to control damages due to salt infiltration. PSC also reduces the extent of alkali-aggregate reactions, besides reducing the heat of hydration due to slower hydration of slag in initial stages. Another important technical advantage associated with these cements is an increase in fluidity in fresh concrete, because of a slower rate of hydration of PSC. This allows increased packing density, besides allowing various service conditions to be met effectively. However, considering the hardness of GBFS, it is expected that efficiency of the grinding mills may decline with a considerable increase in specific power consumption during finish grinding of PSC.

As per the current practice, slag is ground in a vertical roller mill/roller press, thereby reducing the specific power consumption substantially compared to grinding in a ball mill. The ground slag is blended with OPC which has been ground separately. In terms of total power consumption per tonne of cement, slag replacing clinker substantially reduces specific power consumption.

### **Anticipated benefits**

Thermal savings: 270 - 475 kcal/kg PSC

Electrical savings: 18 - 34 kWh/t PSC (from current substitution rate of 40% to allowed/potential level of 70%)

*Note: The above figures have been arrived at by considering the power saving through clinker production with substitution of 40-70% slag, with PSC grinding in a roller press in finish mode.*

CO<sub>2</sub> reduction (direct): Reduction in CO<sub>2</sub> emission up to 325 to 570 kg CO<sub>2</sub>/t PSC (assuming GBFS as CO<sub>2</sub> free)

CO<sub>2</sub> reduction (indirect): 1 kWh reduction in specific power consumption reduces CO<sub>2</sub> emission by 1kg hence, reduction in CO<sub>2</sub> emission is expected to be 18 - 34 kg/t PSC (for cement with 40 - 70% by mass of slag)

*Note: The above thermal/electrical savings are worked out considering OPC (95% clinker) as base level, 40% slag as current national average in PSC, and 70% slag as achievable target in future*

### **Primary influencing parameters**

- ❖ Inadequate infrastructure for granulation of slag
- ❖ Current quality of clinker to absorb additional slag

### **Cost estimation**

Investment cost depends on the size of silo, grinding equipment VRM/roller press, type of handling equipment at plant and so on. The current estimated cost of the slag grinding section is in the range of INR 900-1,100 million (approximately USD 18 - 22 million) for a mill capacity of 100-120 tph slag.

## Conditions, barriers and constraints

Logistical barriers and issues related to policy initiatives for the utilization of slag in cement and concrete largely depend upon factors such as the availability of good quality GBFS in a dry state, the extent of variation in the quality of slag, and a package of measures, such as tax relief and slag utilization subsidy, will go far to promote its utilization. Such barriers are:

### Technical

- ❖ A competitive situation concerning GBFS use e.g. GBFS can also be used as a decarbonated raw material for clinker production or as basic material for future production of geopolymers
- ❖ New steel plants to be set up in 100% slag granulation facility
- ❖ Technology upgrades to improve clinker quality
- ❖ Economic activation of non-granulated blast furnace slag is not available at present. To improve the availability of this type of slag could take a long time, but activation processes like fine grinding using nano-technology and re-sintering and quenching could help

### Policy

- ❖ Provision for transportation of slag in closed wagons to prevent high transit losses as it is a fine powder
- ❖ Limitation in distance over which the slag can be commercially transported
- ❖ Lack of consumer awareness on quality of slag-based cements including its color

### Financial

- ❖ Currently the cost of slag and the freight cost mean bringing slag to the plant is not economically viable. Fiscal incentives will help to increase the slag usage and slag absorption in cement manufacture, as well as saving valuable limestone reserves

## Technology paper no. 15: Reducing clinker factor by using other blending materials

### Current status

In India, various non-ferrous industries, such as the copper industry, lead-zinc smelters, refineries, mineral processing industries and so on, generate industrial wastes that are unutilized, and thus occupy large tracts of valuable land, posing serious environmental and health hazards. Cement manufacturing offers a value-added option to gainfully utilize industrial wastes. Initial studies have shown that these materials have the potential to be used as blending materials at the clinker grinding stage during cement manufacture. Since these materials are added after the clinkerization stage, they substantially reduce heat consumption and mitigate CO<sub>2</sub> emission levels to the extent of the additional levels used.

There are materials, such as dolomite, dolomitic limestone (available in the cement plant site), various types of industrial wastes and by-products, such as lead-zinc slag (~ 1.0 MTPA), copper slag (~0.8 million tonnes per annum (MTPA)), 'LD' / Blast Oxygen Furnace Slag (BOF) slag (~4.0 MTPA), equilibrium catalyst (~ 15,000 TPA), jarosite (~ 0.3 MTPA), kimberlite (~0.6 MTPA), marble slurry (~ 5 MTPA), among others which have shown potential for use as blending components. Research has been conducted on the technical suitability of these materials for use as blending components and the results are very encouraging, indicating the potential use of lead-zinc slag up to 5%, copper slag up to 5%, and equilibrium catalyst up to 15%. As these materials are not included in the Bureau of Indian Standards (Gol) list for use in the grinding stage, they cannot be utilized in the manufacture of cement blends until approved by BIS.

Further, dolomite is untried as a blending component owing to its magnesium oxide (MgO) content. Due to this, insufficient attention has been paid to the development of Portland Dolomite Cement (PDC). Dolomite is abundantly available in many quarries in close proximity to cement plants. However, it is currently unused in clinker production or as a main constituent in cement because of limitations in the MgO content. In fact this material is a resource which is mineralogically quite similar to limestone and is therefore a potential material for cement manufacture. However, there is currently no provision to include dolomite or dolomitic limestone in cement manufacture as it is not included in BIS standards. India has significant deposits of limestone with lower CaCO<sub>3</sub> content as well as abundant inclusions of dolomite/dolomitic limestone. Currently, in India, dolomite is not utilized as a cementitious material because it is not included in the standards. A few studies have been conducted and the results are highly encouraging, and, where use of dolomite up to 20% has been reported, the performance of cement has been comparable to that of Portland Limestone Cement (PLC).

PDC and cement blends containing other potential blending materials can be manufactured by conventional grinding facilities. There is no need for extra budgeting for manufacturing this, except for provision for material handling costs. The products have good economic potential as well as potential benefit in terms of environmental improvement i.e. reduction of Greenhouse Gas (GHG) emissions. Other aspects, such as the presence of heavy metals and their leachability into groundwater have yet to be studied and fully understood.

## Anticipated benefits

Thermal savings: 35 - 100 kcal/kg cement blend, depending on the type of blending material.

Based on utilization level of

- ❖ Lead zinc slag: up to 5%
- ❖ Copper slag: up to 5%
- ❖ E-cat: up to 15%
- ❖ Basalt: up to 15%

Electrical savings: 2.5 - 5 kWh/t cement blend

CO<sub>2</sub> reduction (direct): 10 - 35 kg/t cement blend (for a cement blend with 5 - 15% by mass of above waste as blending material)

CO<sub>2</sub> reduction (indirect): 2.5 - 5 kg/t cement blend (for a cement blend with 5 - 15% by mass of above waste as blending material)

## Primary influencing parameters

- ❖ Quality of clinker currently being produced in India
- ❖ Quantity and quality variation of dolomite and other blending materials
- ❖ Lack of systematic and thorough studies/investigations

## Cost estimation

Estimated handling and storage cost by industrial waste may be approximately INR 10-15 million (approximately USD 200,000-300,000)

## Condition, barriers and constraints

Although there are numerous benefits associated with the use of dolomite, dolomitic limestone and other industrial wastes and their by-products, there are a few issues which need to be addressed as under:

Technical

- ❖ Non-availability of reliable basic data on cement blend characteristics (containing above mentioned materials) and its performance in Indian context. Further research is required

Policy

- ❖ Non-availability of Indian standard specification on the use of these materials
- ❖ Lack of consumer awareness about their benefits

Financial

- ❖ Currently there is uncertainty in cost of the blending materials mentioned above. Fiscal incentives will help to increase their usage and absorption in cement manufacture, as well as saving valuable limestone reserves



## Technology paper no. 16: Reducing clinker factor by using low grade limestone

### Current status

In order to reduce the Greenhouse Gas (GHG) emissions from the cement industry, the percentage of clinker in cement blends can also be reduced by using various other materials, such as limestone, low grade/dolomitic limestone, which are available at the cement manufacturing site itself.

European Standard EN 197-1:2000 specifies various cement types using Ordinary Portland Cement (OPC) clinker and different mineral additives, namely ground granulated blast furnace slag, silica fume, natural and industrial pozzolana, siliceous and calcareous fly ash, burnt shale and limestone. In India, cement types specified in BIS, apart from special cements, include only OPC (three grades), Portland Slag Cement (PSC) and Portland Pozzolana Cement (PPC). The large number of cement types specified in EN 197-1 is generally helpful in achieving cements with tailor-made performance, at the same time permitting a greater number of mineral additives in different combinations, thereby providing greater sustainability, a larger and wider raw material base and the conservation of traditional raw materials. Globally, three types of blended cements, namely PSC, PPC and Portland Limestone Cement (PLC) are being produced. Out of these three, the first two are commonly produced in India and the third type is yet to be produced and standardized by the Bureau of Indian Standards (Gol) as a national standard.

PLC has a good techno-economic potential using low/marginal grade limestone, dolomitic limestone and so on. The product can be made with conventional grinding facilities, provided the required 'know-how' and 'do-how' are available. PLC is fairly popular in the USA and Europe and has been standardized and codified in European standards (EN). It is a type of blended cement on similar lines to PSC and PPC. As per European standard EN-197-1, two types of Portland limestone cement containing 6-20% limestone (type II/A-L) and 21-35% limestone (type II/B-L) are specified and produced. PLCs have many advantages:

1. Reducing GHG emissions during cement manufacture
2. Conserving fast-depleting cement grade limestone reserves
3. Utilizing hitherto unused low grade limestone not suitable for cement manufacture
4. Reducing energy consumption during finish grinding (limestone being softer to grind compared to clinker)

PLC has strong positive environmental credentials. This cement type accounts for more than 40% of the European cement market. However, this cement has not yet been produced in the Indian cement industry. In fact, there is no BIS specification for PLC in India. A systematic and thorough study is required to establish PLC in the Indian context.

It is important to distinguish between PLC and OPC containing a small proportion of limestone as a performance improver. IS 8112:1989 and IS 12269:1987 permit the incorporation of 5% limestone by mass as a performance improver in OPC. If Portland cement contains limestone as a performance improver, it is still classified as a Portland cement. The limestone used as a performance improver should necessarily have more than 75% CaCO<sub>3</sub> content.

PLC can be manufactured by conventional grinding facilities. There is no need for extra budget for manufacturing PLC except a provision for material handling costs. The product has a potential benefit in terms of environmental improvement i.e, reducing GHG emissions to the extent of clinker replacement by limestone in a similar manner to that of fly ash in PPC.

## Anticipated benefits

Thermal savings: up to 170 kcal/kg cement PLC (up to 25% clinker replacement by limestone)

Electrical savings: up to 11 kWh/t PLC

*Note: The above thermal/electrical savings are worked out considering OPC as base level, 25% limestone use replacing clinker in resultant cement blends.*

CO<sub>2</sub> reduction (direct): up to 200kg CO<sub>2</sub>/t PLC (for PLC cement with 25% by mass of limestone)

CO<sub>2</sub> reduction (indirect): 11 Kg CO<sub>2</sub>/t PLC (for PLC cement with 25% by mass of limestone)

## Primary influencing parameters

- ❖ Quality of clinker and limestone

## Cost estimation

Cost for additive limestone storage and handling for feeding into cement

## Conditions, barriers and constraints:

### Technical

- ❖ Non-availability of reliable basic data on low grade limestone characteristics and performance in the Indian context: further research is required

### Policy

- ❖ Non-availability of Indian standard specification on PLC
- ❖ Lack of awareness amongst consumers about their benefits.

### Financial

- ❖ None to date

## Technology paper no. 17: Belite cement from low grade limestone

### Introduction

The mineral phases present in belite cement are same as in Ordinary Portland Cement (OPC) i.e.  $C_2S$ ,  $C_3S$ ,  $C_3A$  and  $C_4AF$ . However, compared to OPC, the  $C_2S$  phase is higher in quantity than that of  $C_3S$  and is more reactive than the conventional  $C_2S$  observed in OPC clinker. In general, the temperature of clinkerization of belite clinker is about 50-100°C lower than that of OPC clinker. Because it contains less alite, the Lime Saturation Factor (LSF) of clinker is maintained at a lower range (0.78-0.83) and the silica modulus is generally kept at a higher range (2.75-3.50) than OPC clinker. Belite clinkers typically have lower free lime.

The raw materials required in the manufacture of belite cements are generally low-grade limestone and additives containing higher amounts of  $Fe_2O_3$  and  $Al_2O_3$ , including industrial by-products. Other materials like  $CaF_2$ ,  $CaSO_4$ ,  $BaO$ ,  $Cr_2O_3$ , alkali etc. have also reportedly been used in small amounts to stabilize the reactive phase and achieve early strength. Very active belite clinker is reported to be produced from chalky and marly raw materials. The microstructure of such belite clinkers shows extremely small dimensions of  $C_2S$ . The belite cement produced from marly limestone, when ground to a fineness of 320 m<sup>2</sup>/kg, showed compressive strength of 16-22 MPa at 3 days and 50-60 MPa at 28 days. The rapid cooling of belite clinker yields higher reactivity due to controlled microstructural developments. It was found that  $\beta$ - $C_2S$  phase containing 1.0%  $B_2O_3$  as mineralizer was more hydraulic than  $C_2S$  containing 1.0%  $Cr_2O_3$  due to specific morphological features in such clinker. In order to achieve adequate quality of belite clinker, the optimum cooling rate reported is 1,000°C/minute in the temperature range of 1,300-900°C.

Keeping LSF on the lower side, particularly in the case of belite cement, is beneficial as it conserves reserves of good quality limestone as well as reducing greenhouse gas (GHG) emissions per tonne of clinker due to lower limestone calcinations. In addition, raw mixes used to produce belite clinker with a lower LSF require lower burning temperatures (they are termed as soft burning mixes), which results in reduced heat consumption and thus contributes further to GHG emissions reductions per tonne of clinker.

### Current status

Despite reduced GHG emissions and maintenance of high quality limestone reserves, the disadvantage of high belite clinker with low LSF, compared to normal OPC clinker with high LSF, is the reduced content of alite and the relatively increased content of belite, as well as the consequential lower early strength at an equal fineness level of cement. However, such reduction in early strength can be made up to a limited extent by finer grinding of the cement, which in turn requires additional electrical energy and also affects mill output. Further, clinker with lower LSF is found to contain a higher amount of belite, which is relatively harder to grind than alite. This increases the clinker grindability index and in turn more energy is required during grinding. This is case-specific. High belite cement is reportedly produced in countries including China, Germany, Japan, Poland and Russia. In the Indian context, it is of utmost importance that systematic and thorough studies are conducted with Indian raw materials, particularly low grade limestone, to address all the issues discussed above.

### Anticipated benefits

Thermal savings: thermal energy consumption likely to be decreased

Electrical savings: electrical energy consumption likely to be increased

CO<sub>2</sub> reduction potential: overall ~10 %

Note: the prominent parameters which could reduce thermal energy consumption while producing belite clinker with low a LSF are lower burning temperatures requiring lower fuel (coal), and a lower lime content in raw mixes requiring low grade limestone. The prominent parameters which could increase the electrical energy consumption are higher grinding energy due to increased belite content in clinker, and finer grinding of cement to achieve similar performance. The parameter which affects both thermal and energy consumption is the reduced scope for the addition of pozzolana such as fly ash (if possible). The consumption depends on the quality of pozzolana of high belite clinker. Therefore the overall impact of high belite clinker technology on GHG emissions has to be fully studied to establish the net gain or loss of thermal and electrical consumption on a case by case basis.

### **Primary influencing parameters**

- ❖ Quality of clinker with low LSF and scope of pozzolana addition
- ❖ Increased grinding energy due to belite rich clinker
- ❖ Requirement of early strength development in cement
- ❖ Level of awareness of belite cement among consumers

### **Cost estimation**

- ❖ No specific investments are anticipated
- ❖ The net gain or loss can be estimated only on case by case basis

### **Conditions, barriers and constraints**

#### Technical

- ❖ Market acceptance of belite rich cement
- ❖ Non-availability of viable technologies to substantially enhance the intrinsic low reactivity of the belite phase and to generate large surface area for the cement at a reasonable energy input to achieve a higher degree of hydration in concrete
- ❖ Poor grindability due to high belite formation in clinker
- ❖ Decrease in mill output due to increased fine grinding of cement from high belite clinker to achieve the development of early (particularly one-day) strength

#### Policy

- ❖ None to date

#### Financial

- ❖ None to date

#### References

H Justnes, 'Principles of making cement with reduced CO<sub>2</sub> emissions', October 2007, SINTEF Building and Infrastructure, Concrete Innovation Centre, Norway (SBF BK A07019)

AK Chatterjee, 'High Belite Portland Cement: an Update on Development, Characterisation and Applications', Proceedings of the 11th International Congress on the Chemistry of Cement (ICCC), Vol. I, pp 45-62, October 2003, Durban, South Africa

## Technology paper no. 18: Alternative de-carbonated raw materials for clinker production

### Current status

The utilization of alternative raw materials containing calcium, which are either de-carbonated or contain calcium as non-carbonate minerals, provides a technically sound alternative for reducing Greenhouse Gas (GHG) emissions. The use of de-carbonated/non-carbonate lime-bearing raw materials on one hand leads to the reduction of GHG emissions, and on the other hand reduces the energy required for de-carbonation of such raw materials. The thermal studies carried out on various carbonates containing raw materials particularly limestone, have established that up to 45% of the total thermal energy is consumed in the process of de-carbonation. Therefore the use of de-carbonated/ non-carbonate source of calcium bearing raw materials offers direct reductions in GHG emissions as well as in fuel consumption. Some of the potential de-carbonated raw materials or non-carbonate raw materials are fly ash, blast furnace slag, steel slag, carbide sludge, lime sludge from paper plants, lime from shaft kilns, phosphogypsum, Pb-Zn slag and so on. The presence of lime in these materials is in non-carbonate mineral forms, such as portlandite, gypsum, calcium aluminate, among others. The level of their utilization will depend upon their overall compatibility with other raw materials, and the desired quality in the resultant clinker. These de-carbonated industrial wastes or non-carbonate wastes may also contain some of the deleterious oxides in the form of  $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$ , sulfur and chlorides, and these become the limiting factors for their use as raw materials in cement manufacture.

Since these oxides are volatile in the rotary kiln during pyro-processing, a careful balancing of these oxides is required to ensure the smooth operation of the cement kiln. Besides, the industrial wastes may also contain heavy and trace elements depending upon origin and therefore a systematic study is required to establish their fixation in the clinker matrix and leaching behavior, if any, in concrete.

At present, sustainable availability of compatible de-carbonated/non-carbonate lime-bearing raw materials and their use in India is limited due to various constraints, such as high power consumption for grinding, high moisture content, presence of deleterious components including heavy metals and so on. Some studies have reported the use of various slags generated from ferrous and non-ferrous industries as raw materials with benefits as mineralizers. The use of fly ash as a source of silica up to 3% is now being practiced in Indian cement plants. There is a need to inventorize de-carbonated/non-carbonate bearing raw materials, their source, annual generation, through high quality and systematic studies taken up to assess their suitability in cement manufacture. The various potential materials and their range of addition as raw materials in cement raw mix are given below:

Potential materials	Current estimated generation (MTPA)	Range of addition as raw mix component (%)
Fly ash	190	1 - 3
Blast furnace slag	22	10 - 15
Steel slag	6	10
Carbide sludge	0.2	10 - 17
Phospho-gypsum	5 - 6	Not available
Pb-Zn slag	1.0	5 - 6
Flue dust from blast furnace	Not available	1 - 2
Dolochar waste	Not available	1 - 3

The benefits include the scope for using more industrial wastes and sub-grade raw materials, thus reducing the cost of cement production. Additional capital cost will be required for infrastructure such as extra storage capacity and handling of such materials.

### **Anticipated benefits**

Thermal savings: reduction in thermal energy consumption to the extent of substitution of main raw material component, viz. limestone. Some of these materials contain a high amount of moisture and therefore the thermal savings will be affected to that extent.

Electrical savings: yet to be established

CO<sub>2</sub> reduction (direct): for every 1% of conventional limestone substitution by dried de-carbonated material, the CO<sub>2</sub> reduction shall be up to 5.25 kg/tonne of clinker or up to 8.0 kg/tonne of cement

CO<sub>2</sub> reduction (indirect): savings are variable based on the type of material and the extent of processing required

### **Primary influencing parameters**

- ❖ Long-term and consistent availability of de-carbonated/non-carbonate lime-bearing raw materials
- ❖ Characteristics of such materials
- ❖ Calcium content as well as other main elements of the alternative de-carbonated/non-carbonate lime-bearing raw materials
- ❖ De-carbonated/non-carbonate portion of calcium content
- ❖ Additional cost for pre-treatment of the material, if required

### **Cost estimation**

Cost of storage and handling of de-carbonated raw materials for clinker production

### **Conditions, barriers and constraints**

#### Technical

- ❖ The potential utilization of de-carbonated material is generally determined on site and will therefore be plant-specific
- ❖ Efficiency is determined by de-carbonated fraction, which may vary strongly even for the same material, e.g., in the case of concrete crusher sand
- ❖ Further treatment steps may improve the utilization, but need to be checked in terms of costs and environmental impacts
- ❖ Space for storage may be an issue

#### Policy

- ❖ Industry-specific guidelines to be issued in collaboration with the National Council for Cement and Building Materials (NCB) / Central Pollution Control Board (CPCB) to dispose of lime-bearing waste material for usage in the cement industry, which will help in conserving the limestone reserves

#### Financial

- ❖ Fiscal incentives are required to compensate capex and operating costs of pre-processing these materials for use in cement plants

## Technology paper no. 19: Improving the burnability of raw mix by use of mineralizer

### Current status

The potential use of mineralizers to improve clinker quality and facilitate energy conservation in cement manufacture is well-established in view of associated techno-economic aspects. There are two overlapping terms, namely fluxes and mineralizers used in cement manufacture. A 'flux' is an additive that decreases the melting point of the liquid phase formed during the clinkerization process, whereas a 'mineralizer' is a substance that accelerates the reaction rates at all or some stages of clinkerization. Most of the mineralizers act as both fluxes and as catalysts during clinkerization.

The possible reaction of mineralizers can be multifarious and the important ones are summarized as follows:

- ❖ Accelerates the de-carbonation and sintering reactions
- ❖ Lowers the clinkering temperature
- ❖ Broadens or narrows the sintering temperature range
- ❖ Modifies liquid properties, such as viscosity, surface tension and so on
- ❖ Increases the crystallization of the liquid phase
- ❖ Increases clinker balling and ring formation tendency
- ❖ Promotes clinker-refractory interaction
- ❖ Alters the overall burnability and volatility conditions inside the kiln

A large number of oxides are reported to act as mineralizers, when added as a raw mix component during clinkerization. Some of the prominent mineralizers are:

- ❖ Fluorides (viz., NaF,  $MgF_2$ ,  $CaF_2$ ,  $Na_3AlF_6$  etc)
- ❖ Fluorosilicates ( viz.,  $Na_2SiF_6$ ,  $MgSiF_6$ ,  $CaSiF_6$  etc)
- ❖ Chlorides (viz., LiCl,  $CaCl_2$ ,  $MgCl_2$ ,  $ZnCl_2$ ,  $BaCl_2$  etc)
- ❖ Sulphates (viz.,  $CaSO_4$ ,  $BaSO_4$ ,  $FeSO_4$ ,  $ZnSO_4$ ,  $Al_2(SO_4)_3$  etc)
- ❖ Phosphates (viz., apatite, phosphorite etc)
- ❖ Carbonates (viz.,  $K_2CO_3$ ,  $MgCO_3$ ,  $BaCO_3$  etc)
- ❖ Oxides, (viz.,  $B_2O_3$ ,  $Cr_2O_3$ , CuO, ZnO, MgO, MnO,  $TiO_2$  etc)
- ❖ Industrial wastes, such as fly ash, non-ferrous slags etc

Recent studies have established that copper slag, a waste generated during the extraction of copper metal in the mineral processing industry, has potential for use as a mineralizer in cement manufacture. Investigations have established its suitability as a raw material (as a source of iron) in the manufacture of Ordinary Portland Cement (OPC). Burnability studies (at 1,300°C, 1,350°C, 1,400°C and 1,450°C) of different raw mixes designed using conventional raw materials, along with varying doses of copper slag (1.5-2.5%) demonstrated the mineralizing effect of copper slag. The clinkerization reaction was found to be completed at 1,400°C with an improved microstructure in the presence of copper slag, compared to the control mix where phase development was appropriate at a comparatively higher temperature eg 1,450°C.

The mineralizers, in general, have been found to reduce the clinkerization temperature by about 50°C or even higher without compromising clinker quality. Such reduction in clinkering temperature has a direct bearing on the reduction of fuel consumption, besides improvement in clinker morphology. The selection and use of the mineralizers are generally governed by the following considerations:

- ❖ Reaction effects desired
- ❖ Compatibility with a given kiln feed
- ❖ Process adopted
- ❖ Physical form of mineralizers
- ❖ Economic viability of using mineralizers

Occasionally, to suit the requirement of a specific situation, a combination of mineralizers (viz.,  $\text{TiO}_2 + \text{CaF}_2$ ,  $\text{FeSO}_4 + \text{ZnSO}_4$ ,  $\text{CaSO}_4 + \text{MgCO}_3$  etc) are reportedly used. Under practical conditions of clinker burning, both aspects of attainment of the right temperature and the duration of holding the material at this temperature govern the quality of clinker manufactured and fuel consumption. Hence, the effects of mineralizers can be viewed from their influence on:

- ❖ Temperature of initial liquid formation
- ❖ Rate of formation of liquid during burning and duration of its availability
- ❖ Characteristics of the liquid, such as viscosity, surface tension, wetting and the influence of minor oxides such as alkalis,  $\text{SO}_4$  etc on these properties which in turn determine nodulization and solid liquid interface reactions
- ❖ Chemical composition of liquid or liquids (in case of immiscibility) and crystallization characteristics on cooling

### **Anticipated benefits**

Thermal savings (direct): reduction in clinkering temperature by around 50°C, reduction in heat consumption by about 13 kcal/kg clinker

Electrical savings: reduction in power consumption up to 1 kWh/tonne cement

CO<sub>2</sub> reduction (direct): 5 - 15 kg/tonne clinker

Indirect benefits:

- ❖ Scope for using sub grade/low carbonate raw materials
- ❖ Increased lifetime of refractories
- ❖ Clinker quality improvement
- ❖ Scope for using more pozzolanic materials



## Conditions, barriers and constraints

### Technical

Though the use of a mineralizer is a technically attractive option to further economize the cement manufacturing process, there are certain barriers, for example:

- ❖ Additional cost of mineralizer(s)
- ❖ Inconsistent availability or non-availability
- ❖ Problems during pyro-processing
- ❖ Uniform dispersion in raw mix

### Policy

- ❖ None to date

### Financial

- ❖ Capital cost due to requirement of extra storage facility for mineralizer(s)
- ❖ Infrastructure required for mineralizer handling system

## Technology paper no. 20: Fluidized Bed Advanced Cement Kiln System (FAKS)

### Current status

FAKS, the fluidized bed advanced cement kiln system, has been researched and developed to burn low grade coals efficiently, reducing NO<sub>x</sub> emissions significantly and increasing thermal efficiency by resourcefully recovering in-process heat from solids and gases.

FAKS consists of:

1. Suspension Preheater (SP) with calciner (SC): for preheating and calcining raw meals
2. Fluidized Bed Cement Kiln (FCK): for granulating raw meals into granules of 1 ~ 2 mm average diameter and completing clinkering reactions at the high temperature of 1,400°C level, without feeding seed-core clinkers
3. Fluidized Bed Quenching Cooler (FBQ): for quick cooling of the burnt clinker from 1,400°C to 1,000°C in order to obtain high quality clinker
4. Packed Bed Cooler (PBC): for cooling the clinker economically to the specified temperature of 150°C

The most important technology in the system is the granulation control technology. It employs the first 'self-granulation' process. Self-granulation is the process whereby granule cores are generated through the agglomeration of a portion of the raw material, allowing the rest of the raw material to adhere and grow on the core in order to control granulation.

A basic study of FAKS technology was launched in 1984. With a number of subsequent studies, a successful test operation of a 200 t/d plant was completed in 1997. In 2005, a joint demonstration project for capacity 1,000 t/d was launched.

Performance comparison in Japan between conventional technology (rotary kiln) and FAKS technology in terms of environmental improvement is shown:

No.	Parameters	Rotary kiln with Air Quench Cooler (AQC)	FAKS
1	Clinker production capacity (t/d)	1,000	1,000
2	Specific heat consumption (kcal/kg clinker)	715*	715
3	Specific power consumption (kWh/t clinker)	27	36
4	CO <sub>2</sub> emission (g/Nm <sup>3</sup> )	245	220
	CO <sub>2</sub> emission (kg/t clinker) for reference plant (kg/t clinker)	357 314 (calculated)	327
5	NO <sub>2</sub> emission (mgNm <sup>3</sup> )	708	476
6	Exhaust gas flow (Nm <sup>3</sup> /kg clinker)	1.46	1.49

\* Ref. plant for study: 715 kcal/kg clinker

FAKS is expected to be commercially adopted as an innovative, alternative cement production technology to reduce NO<sub>x</sub> emissions.

## Anticipated benefits

CO<sub>2</sub> reduction (direct): 20 - 25 kg/tonne clinker

Other

- ❖ Reduced NO<sub>x</sub> emissions
- ❖ Low capital cost per ton of cement production while fulfilling the stringent NO<sub>x</sub> emission standards
- ❖ Suitable for locations where limestone deposits are limited (less than 20 million tonnes)
- ❖ It is of modular design, so capacity can be increased by multiple units
- ❖ Plant is relatively easier to relocate due to smaller foot print

## Primary influencing parameters

- ❖ Reduced environmental emissions level in terms of NO<sub>x</sub>
- ❖ Low cost technology

## Cost estimation

Compared to a conventional SP kiln for 1,000 tpd, there is reduction of 21% in the construction cost and 26% in operating cost for FAKS

## Conditions, barriers and constraints

Technical

- ❖ Technology currently only applicable for low capacity kiln (up to 1,000 tpd): yet to be established for higher capacity
- ❖ Technology assessment is to be carried out to know whether CO<sub>2</sub> reduction potential is available for higher capacity plants
- ❖ Increased electrical energy consumption by 9 kWh/t clinker (8.5 kWh/t OPC) based on reported data of cement kilns (rotary kiln vs FAKS) in Japan

Policy

- ❖ None to date

Financial

- ❖ None to date

## Technology paper no. 21: Fuel cell technology

### Current status

A fuel cell is a device that converts the chemical energy from a fuel into electricity through a chemical reaction with oxygen or another oxidizing agent. Hydrogen is the most common fuel, but hydrocarbons, such as natural gas and alcohols like methanol are sometimes used. Fuel cells are different from batteries as they require a constant source of fuel and oxygen to operate, but they can produce electricity continually for as long as these inputs are supplied.

Hydrogen may be a clean energy carrier with the potential to replace liquid and gaseous fossil fuels in the coming decades. In recent years, notable progress has been made globally in the development and demonstration of hydrogen energy and fuel cell technologies.

There are several kinds of fuel cells, and each operates differently. But in general terms, hydrogen atoms enter a fuel cell at the anode where a chemical reaction strips them of their electrons. The hydrogen atoms are now 'ionized' and carry a positive electrical charge. The negatively charged electrons provide the current through wires.

Oxygen enters the fuel cell at the cathode, combines with electrons returning from the electrical circuit and hydrogen ions that have traveled through the electrolyte from the anode. In other cell types the oxygen picks up electrons and then travels through the electrolyte to the anode.

The electrolyte plays a key role. It must permit only the suitable ions to pass between the anode and cathode. If free electrons or other substances travelled through the electrolyte, it would disrupt the chemical reaction.

Whether they combine at the anode or cathode, together, hydrogen and oxygen form water, which drains from the cell. As long as a fuel cell is supplied with hydrogen and oxygen, it will generate electricity.

### Hydrogen Production Technologies

Hydrogen can store and deliver usable energy, but it does not exist by itself in nature: it is produced from compounds. Hydrogen is produced using locally available resources.

Hydrogen production technologies fall into three general categories: thermal processes, electrolytic processes, and photolytic processes. Some thermal processes use the energy of resources such as natural gas, coal, or biomass to release hydrogen, which is part of the molecular structure of the resource. In other processes, heat, in combination with closed- chemical cycles, produces hydrogen from feedstocks such as water. These are known as 'thermo-chemical' processes. However, the thermo-chemical process is a long-term technology, which is still in the early stages of development around the world. The steam methane reformation process is most widely used to produce hydrogen for industrial applications.

Distributed natural gas reformation is an important pathway for near-term hydrogen production option. Capital cost of the equipment, as well as operation and maintenance costs, and an improvement in process energy efficiency are key challenges for producing hydrogen at a competitive cost compared to fossil fuel.

Hydrogen fuel cell power may find a place as a green power generation technology in the future after a few successful commercial installations at different capacities. Currently, fuel cell technology in smaller capacity is under commercial trials in different parts of the world. In these, technology suppliers are willing to supply the power with a Power Purchase Agreement at a price comparable to prevailing conventional power cost.

Typically, a 50 MW plant requires ten acres of land and an initial provision of approximately 50,000 liters of fresh water. The water can be recycled and therefore only evaporation and drip losses need to be replenished, which are estimated at approximately 7-8%.

### **Anticipated benefits**

Thermal savings: unknown

Electrical savings: unknown

CO<sub>2</sub> reduction (direct): 1.2 tonne of CO<sub>2</sub> per 1,000 kWh if it is replacing the CPP power, and 0.9 tonne of CO<sub>2</sub> per 1,000 kWh if it is replacing grid power

CO<sub>2</sub> reduction (indirect): unknown

### **Primary influencing parameters**

- ❖ The technology is yet to be fully commercialized

### **Cost estimation**

Capital cost, operation cost and maintenance costs are not disclosed but the commercial viability is assured by the technology provider

### **Conditions, barriers and constraints**

Technical

- ❖ Technology is patented

Policy

- ❖ Fiscal incentives like concessional import duty structure etc should support this green and patented technology

Financial

- ❖ None to date

## Technology paper no. 22: Futuristic comminution technologies

### Current status

Comminution is the most expensive unit operation in the cement industry. The current comminution technology is both energy-intensive and inefficient. The available options for grinding of raw material, fuel and clinker include:

1. Ball mill (in open and closed circuit), which is the least efficient technology
2. Vertical Roller Mill (VRM) - more efficient than ball mills
3. Roller press (in different combinations with separators and ball mills) - more efficient than ball mills
4. Horizontal roller mill - more efficient than ball mills

In the Indian cement industry, the vertical roller mill and roller press, in combination with ball mill, are the preferred options for the majority of cement plants. The existing energy consumption for the above grinding technology options as per prevailing norms is:

Specific energy consumption

	Units	Raw material grinding	Coal grinding	Cement grinding
Ball mill	kWh/t material	17 - 26	25 - 30	30 - 34
VRM	kWh/t material	12 - 20	20 - 23	20 - 23
Roller press (in different modes)	kWh/t material	14 - 18	-	26 - 28

### Innovative work / R&D

Some of the latest developments and innovations in the area of comminution are:

#### Aeroacoustics

An innovative processing technology has been developed that employs aeroacoustics to achieve its grinding functions. Aeroacoustics is the science of acoustic noise generation caused by aerodynamic forces interacting with surfaces. The interacting forces occur in natural events such as tornados and hurricanes. The equipment creates a controlled artificial environment in which the combination of simultaneous physical events caused by aeroacoustics is deployed to reduce the particle size of materials without mechanical force. It reduces brittle and solid materials to dust as well as reducing the moisture content.

The technology developers claim that the maximum capacity is 200-250 tonnes per hour, and that application areas are coal and power, oil and gas, cement and mining.

New technology can replace conventional types of raw material grinding, coal grinding and clinker grinding in the cement industry. The advantages claimed are higher processing efficiency, reduction in processing costs, decrease in energy consumption, decline in maintenance and servicing of equipment, reduction in space requirements, significant savings in capital costs, and reduced moisture without heat required.

#### Ultrasonic comminution

Another latest development in comminution is based on the application of ultrasonic energy. On the basis of a number of patents, a brief description of the technology is as under.

A method of comminuting minerals in a continuous comminution system including the steps:

- a. Crushing the minerals to form mineral particles in the size of 1 - 10 mm
- b. Conveying the crushed mineral particles, along with a stream of cryogenic process fluid, a mixture of condensed hydrocarbon gases and liquid CO<sub>2</sub>, to an ultrasonic comminution apparatus
- c. After comminution a classifier separates particles which are of greater than required size and which are returned for re-treatment
- d. The balance of the particles is conveyed by process fluid to the second ultrasonic comminution apparatus, (similar to the first such apparatus) for further comminution to reach the desired fineness

Further investigations are required for possible implementation in the cement industry.

### **Application of microwave energy for improving comminution efficiency**

There is a potential to use microwave energy as a pretreatment method as it improves steel slag comminution efficiency.

The application of microwave treatment as a preceding step in comminution processes has been recognized in much scientific and industrial literature. Based on the laboratory experiments on grinding steel slag in the ball mill, it can be concluded that microwave treatment significantly influences steel slag comminution kinetics. Further, investigations are required for possible implementation of microwave pretreatment of slag/clinker/other minerals for improving the comminution efficiency.

### **Electroacoustical comminution process**

A noncontact comminution process concept has been developed, involving the application of electric and ultrasonic energy for particle size reduction.

This concept uses a combination of electric and ultrasonic energy. The process has also been termed a two-stage or electroacoustical comminution process. By applying electrical energy to the ore, the rock fractures mostly at grain boundaries. At the same time, the electric shock creates secondary hairline fractures in the ore. An additional application of ultrasonic energy to this ore provides further breakage, and substantial size reduction (grinding) is achieved. The concept was proven on a molybdenum porphyry<sup>2</sup> ore but needs additional study and further development for its application in cement industry.

### **Applying ultrasonic field in a roller mill**

Experimental results obtained by using ultrasound to enhance the performance of a roller mill are very encouraging. The required energy consumption is significantly reduced by careful application of an ultrasonic field in the grinding zone. It is also expected to prolong the life of mechanical components (roller and table).

All the above concepts are futuristic and have good potential. Only aeroacoustics is 'ready for implementation' in cement plants. It is expected that successful implementation of aeroacoustics will reduce the energy consumption substantially. However for a scenario of 2030 or 2050 the evaluation and performance in coming years will decide their suitability.

---

2 Porphyry is a type of deposit used for copper, molybdenum

## **Anticipated benefits**

Thermal and electrical savings: implementation of the technology and outcomes will decide the potential reduction of power consumption

CO<sub>2</sub> reduction potential: implementation of the technology and outcomes will decide the potential reduction of power consumption and resultant CO<sub>2</sub> emission levels.

## **Primary influencing parameters**

- ❖ Proving the technology at industrial scale

## **Cost estimation**

- ❖ These are futuristic technologies and many are yet to reach the commercial stage, hence no cost data is available

## **Conditions, barriers and constraints**

### Technical

- ❖ These technologies (apart from aeroacoustics) are still in the conceptual / pilot plant stage and have not reached the commercial stage. Their application to the cement industry has to be tried and established

### Policy

- ❖ None to date

### Financial

- ❖ Can be established only after commercialization



## Technology Paper no. 23: Carbon capture through algal growth and use of biofuels

### Current status

Several attempts have been made by the cement industry globally to recover carbon dioxide (CO<sub>2</sub>) from the flue gas using physical and chemical methods. The large volume of CO<sub>2</sub> emitted from the kiln stack, generated by calcination and combustion during pyro-processing, has its limitations for reduction. In view of the CO<sub>2</sub> emission level from the cement sector, carbon capture seems to be one of the possible options for tangible CO<sub>2</sub> abatement. However, till date, no solutions for CO<sub>2</sub> capture from the kiln stack have been found to be feasible though several CCS studies have been carried out. Besides technical aspects, the economic frame work will be decisive for future applications of carbon capture in the cement sector. In fact post-combustion capture is an end-of-pipe measure, which wouldn't require any basic modification in the pyro-processing of clinker production. All evaluations so far show that CCS will require a considerable amount of additional energy. To use additional energy in times of dwindling energy resources in order to compensate the impact of energy consumption is at least questionable. This deployment of additional energy for the sole purpose of CO<sub>2</sub> abatement is justified by the lack of alternatives only. At present CCS is far away from being accepted as commercially viable technology at least for cement sector. No industrial installations are in operation on permanent basis in any cement plant except some plant trials and small scale demonstrations by one international cement manufacturer.

Carbon Capture and Storage may become an emerging approach for CO<sub>2</sub> abatement. For the cement industry it means that CO<sub>2</sub> from the combustion of fuels and from the treatment of raw materials could be captured and stored away from the atmosphere for a very long period of time. The European Cement Research Academy (ECRA) taking cognizance of the above took the initiative to take up the study for state-of-the-art CO<sub>2</sub> capture technologies. CCS technologies can be mainly characterized as: Post-combustion capture, Oxy-fuel technology and Pre-combustion capture. The application of CCS makes sense only if the questions about suitable storage sites, the transportation of CO<sub>2</sub>, and the legal and political framework supporting CCS are in place. CCS technologies on an industrial scale will probably not be available before 2025-2030.

However, one of the great potentials for carbon sequestration by a biological system is the well-understood and natural process of the photosynthesis mechanism. Figure-1 shows photosynthesis of algae which reduces carbon in the gas stream by converting it to biomass: which can be carried out either by open pond or closed bioreactor systems in the presence of light. It has been concluded that the open pond system is not viable; hence various groups have designed different bioreactors claiming their efficiencies for small power plants, but no cement plant till date has adopted any technology for sequestration of CO<sub>2</sub>.

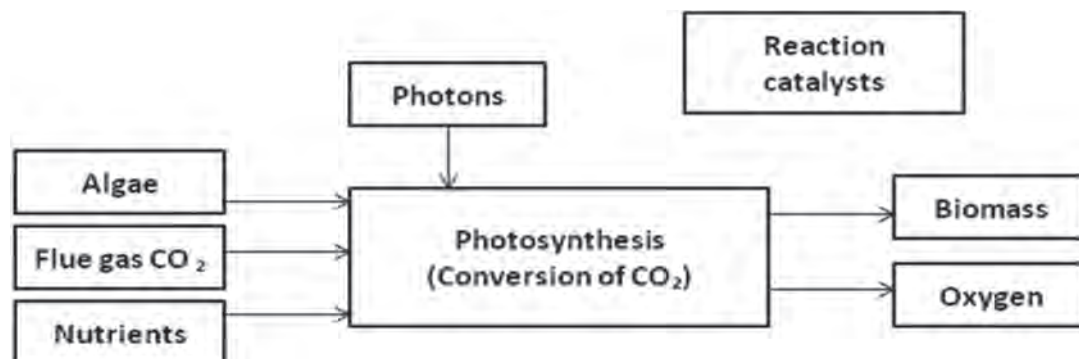


Figure - 1: Photosynthesis Conversion of CO<sub>2</sub> to Biomass

In this biological approach, microalgae appear more photosynthetically efficient than terrestrial plants and are efficient CO<sub>2</sub> sequesterers. Once it was known that microalgae has a potential to consume more CO<sub>2</sub> than atmospheric level, microalgae are used as biological scrubbers to mitigate CO<sub>2</sub> from stack gases from thermal power plants. Microalgae are of great interest because of their rapid growth rate and tolerance to varying environmental conditions like kiln exit gas. The carbon fixed by the microalgae is incorporated into energy rich biomass, which is widely used as an excellent source of lipids, co-firing fuel and as animal feed. Kiln stack gases contain 12-20% CO<sub>2</sub> and also contain some combustible products such as NO<sub>x</sub>, SO<sub>x</sub> which can be effectively used as nutrients by microalgae and thus high purity of the CO<sub>2</sub> is not required for the growth of microalgae. Therefore, direct injection of flue gas into CO<sub>2</sub> sequestration systems can reduce the cost of separation of CO<sub>2</sub> from the flue gas. Several species have been tested for CO<sub>2</sub> sequestration. *Chlorella vulgaris* could grow at 60% CO<sub>2</sub> although maximum growth occurs at 10% CO<sub>2</sub>. *Scenedesmus* species could grow at 80% CO<sub>2</sub> but maximum cell mass was observed at 10-20% CO<sub>2</sub>. Marine microalgae are mostly used for CO<sub>2</sub> sequestration because seawater could be directly used as the medium so that maintenance cost of the culture could be reduced. The marine algal species employed include *Phaeodactylum tricornutum*, *Nanochloropsis salina* and *Chlorococcum littorale*. The temperature of stack gas from thermal power station is around 125-150°C therefore the use of high temperature tolerant algae has been considered for CO<sub>2</sub> sequestration including *Cyanidium caldarium*.

To determine the viability of using microalgae as a CO<sub>2</sub> sequestration option, CO<sub>2</sub> fixation and microalgae growth rates have been reported. It should be noted that current data were taken from microalgae grown in specially constructed photobioreactors (PBRs), or growth chambers, except where it is otherwise specified. Microalgal growth rate ranged from approximately 15-25 g dry biomass per square meter (1 basal area) per day (g dr wt m<sup>2</sup> day<sup>3</sup>), with reports of short-term rates of 50 g dr wt m<sup>2</sup> day (Chelf et al., 1993). In terms of growth per reactor volume, the growth rates ranged from 0.1-1.2 g dry wt m<sup>2</sup> day, with maximum cell concentrations ranging from 0.7-14.4 g dr wt m<sup>2</sup> day (Kurano et al., 1996; Michiki, 1995). Microalgal doubling time (defined as the amount of time for the biomass to double in weight) has been shown to be on the order of hours (2.4-24) for most microalgal samples studied (Sakai et al., 1995; Kurano et al., 1995; Michiki, 1995). Matsumoto et al., (1997) demonstrated that microalgal productivities on a large scale were comparable to productivities achieved during small-scale testing (approximately 8-10 g dry wt m<sup>2</sup> day). In order to obtain high algal production rates, many of the referenced studies harvested the biomass daily. If unharvested, production rates will reach a peak and then decline with increasing biomass concentration because of reduced available light (mutual shading) and depletion of nutrients (Nishikawa et al., 1992). Therefore, harvesting is an essential part of maintaining high microalgal productivity rates. Benemann (1997) asserts that the microalgae growth rates that occur in bioreactors and smallscale ponds cannot be expected in full-scale operating sequestration ponds. Photosynthetic visible light conversion efficiencies in laboratory experiments are often 20-24%, whereas maximum conversion efficiencies of higher plants (such as sugar cane) grown at optimum conditions are only 7-8%. The conversion efficiencies of microalgae are not expected to exceed those of the higher plants. And to achieve those efficiencies would require development of techniques to maintain the original algal strains and ward off invasion by other algae and infections. Tubular photobioreactors and helical photobioreactors for microalgal CO<sub>2</sub> sequestration offer the principal advantage of increased microalgal productivity, owing to controlled environmental conditions such as pH, temperature, CO<sub>2</sub> concentration, etc. It has high surface area to volume ratio and allows better CO<sub>2</sub> transfer from the gas stream to the liquid culture medium. In tubular airlift photobioreactor, circulation is achieved without mechanical agitation and this reduces potential for contamination, also the cell damage associated with mechanical pumping is avoided.

---

3 Unit used: Gram dry weight per square meter per day

When certain thermophilic algae species are used in a bioreactor, presence of light with required nutrients is the key to promoting uniform and maximum growth of biomass. Certain algal strains withstanding higher pH levels, required nutrients and continuously supplied algae was successfully grown in simulated flue gas of composition of 16% CO<sub>2</sub>, 300ppm NO<sub>x</sub>, 40ppm SO<sub>2</sub> and rest of nitrogen gas in laboratory scale with 100 litre capacity tubular photo bioreactor. It has been observed that growth of microcoleous is not effected in presence of SO<sub>2</sub> and NO<sub>x</sub>.

The future roadmap provides an expert consensus of the R&D that needs to be carried out to develop practical microalgae processes that could abate hundreds of millions of tons of fossil CO<sub>2</sub> and other greenhouse gases. Such microalgae processes would use CO<sub>2</sub> from cement plants, which do not need any change in plant configuration, flue gases or similar sources to cultivate specific microalgal species in large bioreactors at high solar conversion efficiencies, with the harvested biomass converted to renewable fuels to replace fossil fuels. The open pond system is not feasible (due to high contamination and high land area requirements). Detailed requirements for the production of algae by bioreactor are given below:

Sl no.	Algae Production (TPD)	1	10	25	50	75	100
1	Installation Area (m <sup>2</sup> )	1,752	7,522	44,555	89,110	113,665	175,200
2	Volume of Storage Tank (m <sup>3</sup> )	333	3,333	8,333	16,667	25,000	33,300
3	Tube* Length (m)	1,068	10,692	26,733	53,466	80,199	106,800
4	Tube* Volume (m <sup>3</sup> )	667	6,667	16,667	33,333	50,000	66,700
5	Power Requirement Electric (kWh/day)	55	545	1,364	2,727	4,091	5,500
6	CO <sub>2</sub> (kg/day)	2,881	28,805	72,013	144,027	216,040	288,100
7	Nitrogen (kg/day)	81	813	2,031	4,063	6,094	8,100

\* Cylindrical Tube diameter (640 mm)

### Anticipated benefits

Thermal savings: generated biofuel will replace fossil fuel

Electrical savings: no effect on electrical energy consumption

CO<sub>2</sub> reduction (direct): high CO<sub>2</sub> absorption potential depending upon the algae - type, volume, technology, conditions

CO<sub>2</sub> reduction (indirect): biofuel generated will replace fossil fuel, and will lead to reduction of CO<sub>2</sub> emissions

### Primary influencing parameters:

- ❖ Only viable if a carbon tax system exists, which will augment CCS initiatives especially in the long-term perspective

## Cost estimation

Further studies are required on cost estimation for open pond as well as bioreactor systems at plant level. But much literature estimates that cost varies from €20 - 75 / tonne of CO<sub>2</sub> for CCS as reported by ECRA. In the Indian context, both ways of carbon capture either by pond or bioreactor for the growth of algae, need further studies in detail.

## Conditions, barriers and constraints

A thorough study and analysis of the existing technologies that employ algae as a means of carbon capture is required, to arrive at most suitable technology(ies) for the Indian scenario.

### Technical

- ❖ Space is required for an open pond system and this will have a severe impact on the land area required by the cement plant, as well as on water requirement. For other bioreactor systems, the requirements of land and water need to be assessed.
- ❖ The existing studies only reveal the success of the algal systems for carbon capture at the laboratory scale. The feasibility of the scaling up of lab-scale systems to industrial scale needs to be studied in India.
- ❖ Certain LCA (Lifecycle Assessment used to study the environmental impacts, energy consumption etc throughout the processes) studies have revealed that the total expenditure of energy in carbon capture, transport, and storage outweighs the advantages of carbon capture. But preliminary studies indicate that especially sequestration of carbon by will benefit carbon captured so as to offset the total energy expenditure as biomass will give thermal energy.

### Policy

- ❖ Policy incentives to the industries for deployment of the CCS technology are essential for industries to adopt it.

### Financial

- ❖ Financial incentives to the industries for deployment of the CCS technology are essential for industries to adopt it.

## References:

1. Chinnasamy S, Ramakrishnan B, Bhatnagar A and Das K C., Biomass Production Potential of a wastewater Algae *Chlorella Vulgaris* ARC 1 Under Elevated level of CO<sub>2</sub> and temperature. *Int. J. Mol. Sci.*, 10:518-532 (2009)
2. Benemann, John R., Biofixation of CO<sub>2</sub> and Greenhouse Gas Abatement with Microalgae Technology Roadmap, U S Department of Energy, National Energy Technology Laboratory, 14th January, (2003)
3. Technical Report TR-ECRA-106/2009 ECRA CCS Project - Report about Phase II – Study about Technical and Financial aspects of CCS Projects, ©European Cement Research Academy, 22 June (2009)
4. Kolijonen, Tiina Sii, Volker Hoenig, Helmut Hoppe, and Bernhard Emberger; Carbon Capture Technology - Options and Potentials for the Cement Industry PCA R&D Serial No. 3022, © European Cement Research Academy, 3rd July (2007)
5. Kolijonen, Tiina Siikavirta, Hanne and Zevenhoven, Ron ; CO<sub>2</sub> Capture, Storage and Utilization in Finland , Project Report : PRO4/T7504/02; VTT processes, Finland. 29th August (2002)
6. Climate Change : Synthesis Report, An assessment of the Intergovernmental Panel on Climate Change (2007)
7. Ono E and Cuello J , Carbon dioxide mitigation using Thermophilic cyanobacteria *Biosyst. Eng.*, 96(1):129-134, (2007)
8. Wang B, Li Y, Wu N and Lan C Q CO<sub>2</sub> Bio-mitigation using microalgae, *Appl Microbiol. Biotechnol.* 79:707-718, (2008)
9. Benemann, J.R. CO<sub>2</sub> Mitigation with Microalgae Systems. *Energy Conversion Manage.* 1997, 38, S475-S479.
10. Brown, L.M. Uptake of Carbon Dioxide from Flue Gas by Microalgae. *Energy Conversion Manage.* 1996, 37, 1363-1367
11. Chelf, P.; Brown, L.M.; Wyman, C.E. Aquatic Biomass Resources and Carbon Dioxide Trapping. *Biomass Bioenergy* 1993, 4, 175-183.
12. Kadam, K.L. Power Plant Flue Gas as a Source of CO<sub>2</sub> for Microalgae Cultivation: Economic
13. Impact of Different Process Options. *Energy Conversion and Management* 1997, 38, S505-S510.
14. Kurano, N.; Ikemoto, H.; Miyashita, H.; Hasegawa, T.; Hata, H.; Miyachi, S. Fixation and Utilization of Carbon Dioxide by Microalgal Photosynthesis. *Energy Conversion and Management* 1996, 36, 689-692
15. Matsumoto, H.; Hamasaki, A.; Sioji, N.; Ikuta, Y. Influence of CO<sub>2</sub>, SO<sub>2</sub>, and NO in Flue Gas on Microalgae Productivity. *J. Chem. Eng. Japan* 1997, 30, 620-324.
16. Michiki, H. Biological CO<sub>2</sub> Fixation and Utilization Project. *Energy Conversion and Management* 1995, 36, 701-705.
17. Nishikawa, N.; Hon-Nami, K.; Hirano, A.; Ikuta, Y.; Hukuda, Y.; Negoro, M.; Kaneko, M.; Hada, M. Reduction of Carbon Dioxide Emission from Flue Gas with Microalgae Cultivation. *Energy Conversion and Management* 1992, 33, 553-560.
18. Sakai, N.; Sakamoto, Y.; Kishimoto, N.; Chihara, M.; Karube, I. *Chlorella* Strains from Hot Springs Tolerant to High Temperature and High CO<sub>2</sub>. *Energy Conversion and Management* 1995, 36, 693-696.

## Technology paper no. 24: Waste Heat Recovery (WHR)

### Current status

Cement manufacture is a high temperature sintering process involving chemical reactions. The limestone ( $\text{CaCO}_3$ ) decomposes into  $\text{CaO}$  and  $\text{CO}_2$  during this process resulting in the release of  $\text{CO}_2$  into the atmosphere. It is estimated that one tonne of  $\text{CaCO}_3$  releases 0.44 tonne of  $\text{CO}_2$  further, coal is used as a fuel in cement manufacture and this results in the discharge of  $\text{CO}_2$  to the atmosphere of about 1.8 - 2.2 tonnes  $\text{CO}_2$  per tonne of coal. Further, captive diesel and thermal power stations also contribute to generation of Greenhouse Gas (GHG) emissions.

Studies indicate that in case of wet process plants, the kiln exit gas has little utility since the temperatures are low (180-200°C) and moisture-laden. However, in the case of dry process cement plants, nearly 40% of the total heat input is available as waste heat from the exit gases of the preheater and cooler. The quantity of heat from pre-heater exit gases ranges from 180–250 kcal/kg clinker at a temperature range of 300-400°C. In addition, 80-130 kcal/kg clinker heat is available at a temperature range of 200-300°C from the exhaust air of the grate cooler. In some cases, it is observed that although the quantity of thermal energy through preheater discharge gases of the grate cooler exhaust is high, the quality of such heat is low. These heats have various applications such as drying of raw material and coal or generation of power.

As raw material drying is important in a cement plant, heat recovery has limited application for plants with higher raw material moisture content. Often drying of other materials such as slag or fly ash requires hot gases from the preheater or cooler and, in that case, waste heat recovery will be further decreased.

Power production utilizing hot gases from the preheater and hot air from the cooler requires a heat recovery boiler and a turbine system. Power generation can be based on a steam process, the Organic Rankine Cycle (ORC) process or the Kalina process. The steam turbine technology is best known from power plants. While in modern power plants, electric efficiency comes up to 45-46%, the relatively low temperature level from the cooler (200-300°C) limits the efficiency to a maximum of 20-25%.

This technology was developed and first implemented in Japan due to high energy costs and relatively low capital cost. Cogeneration systems working on steam cycle for the relatively high temperature preheater exhaust gases and hot water flash cycle for medium temperature gases like that of cooler have been well established in the Japanese cement industry. Cogeneration technologies based on the ORC process for low temperature waste gases have also been commercialized and implemented in Japan. From Japan, the technology is now spreading to other plants, predominantly in China where it has become a kind of standard as a way to respond to industry power supply issues as a part of the national strategy. Relatively high power prices and low project costs have fostered widespread uptake of Waste Heat Recovery (WHR) initiatives in China. The experience in China on WHR for cogeneration of power has shown that, in large plants, about 22-36 kWh/tonne clinker (25-30% of total requirement) can be generated. This power is considered sufficient to operate the kiln section on a sustained basis.

However, in many other regions with unstable power supplies, conventional self-generation solutions, such as Captive Diesel Generators and Captive Thermal Power Stations are still preferred to Waste heat Recovery (WHR) systems. Some interest is growing in Europe for WHR systems, but high project costs are the main barrier. The electrical efficiency of these WHR installations varies from 10-20%. The Organic Rankine Cycle (ORC) and Kalina technologies use organic substances or  $\text{NH}_3$  as cycling media, which evaporate at lower temperatures and can therefore produce electric power at a temperature level at which steam turbines cannot otherwise efficiently manage. Nevertheless, the efficiency is normally less than 15%.



### **Main influencing parameters:**

- ❖ Installed power generation capacity and the extent of shortfall with respect to power demand.
- ❖ Raw material moisture content
- ❖ Type of cooler
- ❖ Heat already used for other purposes (e.g. drying of other materials)
- ❖ WHR generation technology (SRC / ORC)
- ❖ Quality and amount of waste heat available for heat recovery
- ❖ Availability of water

### **Cost estimation**

- ❖ INR 80 - 100 million / MW (approximately USD 1.6 - 2 million)

### **Conditions, barriers and constraints**

#### Technical

- ❖ Number of preheater stages
- ❖ Temperature and amount of waste heat available
- ❖ Availability of space in close proximity to the preheater, cooler and air-cooled condensors

#### Policy

- ❖ Incentivizing the installation of through fiscal incentives applicable for renewable energy as the payback period for WHR is very long and it does not consumer any additional fossil fuel.
- ❖ WHR should be treated as a renewable energy source

#### Financial

- ❖ Relatively high cost of technology compared to conventional system
- ❖ Long payback periods
- ❖ Clean Development Mechanism (CDM) is not available for WHR in the majority of cases



## Technology paper no. 25: Geopolymer cement

### Current status

Geopolymer cements are two component binders consisting of a reactive solid component and an alkaline activator. During the reaction in alkaline media a three-dimensional inorganic aluminosilicate polymer network is built that is responsible for the relatively high strength of the hardened product. The term geopolymer was first used by Davidovits in the 1970s to accentuate the relationship with geological materials.

Aluminosilicates of natural (metakaolin, natural pozzolana) or industrial (fly ashes, granulated blast furnace slags) origin are used as the reactive solid component in geopolymeric cements. The availability of these industrial waste materials are limited and the total quantum of coal combustion residue currently generated by Indian thermal power plants is estimated to be about 190 million tonnes. As a consequence, even if technical barriers are overcome, geopolymers will be produced in limited quantities. Chemically, geopolymers can be divided into two groups depending on their composition: materials containing mainly Al and Si (e.g. metakaolin and siliceous fly ash) and materials containing mainly Ca and Si (e.g. blast furnace slag). Geopolymeric binders of the latter group build calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH) phases, besides the aluminosilicate network, which can cause significant variations in quality, e.g. strength development of the binder.

Metakaolin prepared by sintering the natural clay mineral kaolin was the primary starting material for an alkaline activated poly-condensation and exhibits the highest reactivity of all possible materials. Owing to high production costs, metakaolin will be suitable for special applications only and will not be adapted for broad applications in practice. In addition, the main technical challenge still seems to be maintaining a stable and defined product quality and concrete performance.

No significant production or usage of geopolymeric binders has been reported from India. Reports from abroad indicate that until now, geopolymers have been produced only for demonstration purposes and have only been used in non-structural applications, e.g., paving. Strength development of geopolymeric compositions depends on several factors (Duxon et al, 2007) and further studies are required to understand and control the impact of these factors, which include material composition and mineralogy, fineness, activator content, curing regime and so on to develop suitable application of geopolymeric materials. Techniques for the mass production of geopolymers have been suggested, and a first industrial plant has been built in Australia (Nowak et al, 2008). The expected CO<sub>2</sub> emissions are 300 kg CO<sub>2</sub>/t of product (or 70% less than typical OPC). However, this does not take into account emissions due to the production of the activators (e.g. sodium silicate). These contribute significantly to life cycle inventory, but data are not available for these materials. Therefore, based on today's knowledge, it is not possible to assess the reduction potential of materials like granulated blast furnace slag and fly ash used as clinker substitute or as a basis for geopolymers.

### Anticipated benefits

Thermal savings: reduction potential depends strongly on energy demand for activator production

Electrical savings: reduction potential depends strongly on energy demand for activator production

CO<sub>2</sub> reduction (direct): depends strongly on CO<sub>2</sub> emission from activator production

CO<sub>2</sub> reduction (indirect): depends strongly on CO<sub>2</sub> emission from activator production

Alkali-activated systems are claimed to reduce direct CO<sub>2</sub> emissions up to 80% compared to OPC. This does not, however, include emissions from activator and clay production.

## Primary influencing parameters

- ❖ Choice and/or production of the reactive starting materials
- ❖ Production of the alkaline activators

## Cost estimation

Currently unknown - needs to be determined and will strongly depend on:

- ❖ Availability and processing of starting materials
- ❖ Costs for alkaline activators
- ❖ Development of applications of alkali-activated systems

Operational costs are reported to be 20% higher than for OPC production in the literature.

## Conditions, barriers and constraints

### Technical

- ❖ The properties of geopolymer cements strongly depend on the starting material, its chemical composition, temperature etc. This can lead to variations in the workability (e.g. setting time) and in other properties of the concrete like strength development
- ❖ The durability of the concrete is yet to be demonstrated
- ❖ The reactive components, like fly ash and slag, are industrial waste products and their availability depends on the future of coal-fired power plants and future steel production

### Policy

- ❖ Operational safety while working with highly alkaline conditions has to be assured

### Financial

- ❖ Production quantities and costs for the alkaline activator (e.g. sodium silicate) will play an important role in the production of geopolymer cements

## References

1. Duxson P., Fernandez-Jimenez A., Provis J.L., Lukey G.C., Palomo A. and van Deventer J.S.J., Geopolymer technology: the current state of the art, *J. Mater. Sci.* 42, 2719-2933, 2007
2. Nowak, R., Geopolymer concrete opens to reduce CO<sub>2</sub> emissions, *New Scientist*, 197, 28-29, 2008

## Technology paper no. 26: Use of nanotechnology in cement production

### Current status

Nanotechnology can be defined as the study and manipulation of the properties and structure of matter at nanoscale. Cement hydration products, which provide the concrete and its important properties, such as strength and shrinkage have nanoscale structures, which are yet to be understood completely. Applications of nanosciences and nanotechnology in the study and further development of cement, alternative cementitious binders and concrete are being made for achieving cements and concretes with improved performance as well as greater sustainability. The efforts are currently directed towards:

- ❖ Development of nano-cements and eco-friendly, high performance cements/binders manufactured with lower clinker content
- ❖ Improvement in cement and concrete performance through incorporation of nanoparticles and chemical admixture
- ❖ Better understanding of cementitious materials through nanoscale investigations of cement hydration reactions and hydration products to achieve cements and concretes with tailor-made performance
- ❖ Development of activators/catalysts for low temperature clinkerization
- ❖ Use of nanoparticles for the reinforcement of the cementitious matrix for improved flexibility and toughness
- ❖ Application of photocatalytic  $\text{TiO}_2$  nanoparticles for self-cleaning concrete surfaces
- ❖ Cement based nano-composites for various applications

Nano-cements are being developed as cements containing well dispersed nano-sized particles of cement and mineral admixtures. The nanoparticles would be evenly distributed among the larger particles of mineral admixtures and with such fine dispersion that even a lower content of cement should be able to provide the desired binding of aggregates and admixture particles generating required strength and performance. In such systems the mineral additives can be utilized in larger quantity. Nano-cements therefore have the potential to provide significant saving of cement and lower  $\text{CO}_2$  emissions. There are few reports on the development of nano-catalysts for low temperature clinkerization and efficient grinding aids. Mechano-chemical activation of raw materials and cements may provide enhanced reactivity during clinkerization and hydration, respectively. The most studied and well-reported area is the use of nanoparticles, such as nano-silica in cement mortar and concrete.

Various approaches have been suggested for obtaining nano-sized particles of cement including colloidal milling of portland cement clinker. A one-step process to manufacture typical Ordinary Portland Cement (OPC) in the form of nanoparticles using flame spray pyrolysis has also been reported. The reactivity of these nano-cement particles was found to be very high as compared to the reactivity of micron sized traditional cement particles. Concurrently, nanoparticles cause a sharp increase in normal consistency of cement and therefore efficient chemical admixtures would be required for workability control. It has been suggested that the admixtures may be blended or inter-ground with dry cement powder for better compatibility and efficiency. Inter-grinding cement and appropriate dry chemical admixtures in a high-energy mill results in both reduced water demand and high strength.

Incorporation of nanoparticles of silica and iron oxide in cement and concrete has been reported to result in significant improvements in microstructure and strength, especially early strength, of cement mortar and concrete. Improvement in the microstructure of concrete is expected to provide enhanced durability characteristics and longer service life of the structure and thus adding to sustainability. The maximum content of nanoparticles is generally limited to 3-6% by mass of cement, though the effect of higher contents, up to 12% has also been reported.

The R&D efforts for nanoscale investigations of cements and concrete and developing nanotechnology-based new products needs to be further accelerated to achieve greater sustainability to produce cements and concretes with lower clinker content or enhanced performance. Investigations into the role of nanoparticles of different sizes and varying materials in modifying the properties of cementitious binders and concrete, and on the safe handling of nanoparticles, may provide useful results, leading to improved cements and special concretes with enhanced durability. Investigations into the use of nanoparticles of silica, alumina, iron oxide and titanium dioxide with sizes of particles in the range of 15 nanometers and above have been reported (Harsh et al, 2011). Investigations carried out have indicated a 25-50% increase in the 3 day compressive strength of Portland Pozzolana Cement (PPC) and Ordinary Portland Cement (OPC) blends incorporating 5% of nanosilica particles of average particle size of 15 nanometers. The present high cost of nanoparticles needs to be brought down for favorable economics of their utilization and R&D efforts are therefore also required for developing economic processes for the production of nanoparticles including carbon nano-tubes. Currently, there is not much reported work on nano-catalysts for low temperature clinkerization, but the available information indicates that further work in this direction may be fruitful.

The application of nanotechnology to the production of cement and concrete is expected to yield several benefits, reduction in CO<sub>2</sub> emission being one of them (Harsh et al, 2011). Other expected benefits include cements with improved performance and more durable concretes. R&D efforts should therefore be continued to achieve these objectives through the applications of nanotechnology to cement and concrete production.

### **Anticipated benefits**

Thermal and electrical savings: the technology is in a pilot stage and not yet commercialized, therefore figures of potential savings are not published

CO<sub>2</sub> reduction potential: the technology is in a pilot stage and not yet commercialized, therefore figures of potential savings are not published

### **Primary influencing parameters**

The technologies are still under development, with the potential for reduction of clinker in cement and CO<sub>2</sub> emissions reductions

### **Conditions, barriers and constraints**

Technical

- ❖ The health hazards associated with handling and use of nanoparticles need to be studied

Policy

- ❖ None to date

Financial

- ❖ Present cost of production of nanoparticles is very high and needs to be brought down for economic utilization

## References:

1. S Harsh, A K Arora, M M Ali and M Vasudeva, 'Investigations on nanosilica blended cements', 13th International Congress on the Chemistry of Cements, July 2011, Madrid.
2. S Harsh, M M Ali and A Pahuja, 'Applications of nanotechnology in cement and concrete for greater sustainability', NCB-CMA Special Publication, 12 NCB International Seminar, November 2011, New Delhi.

## Technology paper no: 27: Developing national standards on composite cements

### Current status

Blended cements, which are produced using more than one mineral addition, are known as 'composite cement'. At present, the Bureau of Indian Standards (Gol) has no specific standard for composite cements. European standards identify composite cements (CEM V), where both granulated blast furnace slag (GBFS) and siliceous fly ash/pozzolanic material are used together as cement replacement materials. For the European cement type 'Portland Composite Cement (type II /A-M and II /B-M)', European Standard EN 197 specifies the use of a number of mineral admixtures such as GGBFS, silica fume, natural and industrial pozzolana, siliceous and calcareous fly ash, burnt clay, limestone, etc. in the range of 6-20 % for type II/A-M and 21-35 % for type II/B-M cements respectively. The American Society for Testing of Materials (ASTM) has also introduced performance-based specifications for hydraulic cements with no restrictions on cement composition (ASTM C 1157-00, Standard Performance Specification for Hydraulic Cement). Such freedom in the choice of mineral additives is useful for both optimizing/controlling the performance of cement and maximizing the use of mineral admixtures leading to lower CO<sub>2</sub> emissions and greater sustainability.

To facilitate the manufacture and use of composite cement in India it is required to formulate the standards for composite cements. Investigations on performance and durability characteristics of composite cements prepared from indigenous materials and tested as per BIS specifications would be required to generate enough data to enable formulation of standards on composite cements. A study on composite cements prepared using GBFS and fly ash indicates that cements prepared using granulated blast furnace slag and fly ash along with clinker and gypsum, depending on the proportion of constituents used, can have physical properties in the same range as specified for Portland Pozzolana Cement (PPC) and Portland Slag Cement (PSC) by IS 1489:1991 and IS 455:1989, respectively. The results indicated that the physical properties of composite cement prepared using 40-60% clinker and 20-30% each of fly ash and GBFS were in the range specified for PPC and PSC by respective Indian standards. Further work on preparation and performance evaluation of composite cements including their hydration and long-term durability characteristics and effect on properties of fresh and hardened concrete is required at this stage to enable better understanding of these cements and the formulation of national standards on composite cements.

Besides the composition, particle size distribution is another important factor influencing cement properties. The grindability of constituents used in the production of composite cements may differ greatly from each other. Thus, a perfect particle size distribution of cement may not be easy to obtain with the process of inter-grinding. Advantages/disadvantages of intergrinding and separate grinding and blending in manufacture of multi-component blended cements would also need to be investigated.

### Anticipated benefits

Thermal and electrical savings: apart from thermal energy, there will be a specific electrical energy reduction per tonne of cement, which will indirectly reduce the Scope II CO<sub>2</sub> emissions if the plant does not have CPP. If the plant has CPP, it will reduce Scope I CO<sub>2</sub> emissions.

Thermal savings reduction potential depends on clinker substitution level achieved:

<b>Clinker substitution</b>	<b>25%</b>	<b>35%</b>	<b>45%</b>	<b>55%</b>	<b>70%</b>
<b>Thermal saving (kcal/kg cement)</b>	170	235	305	375	475
<b>CO<sub>2</sub> reduction potential (kg CO<sub>2</sub> / tonne cement)</b>	205	285	370	450	575

### **Primary influencing parameters**

- ❖ Availability of blending components

### **Cost estimation**

Cost to be assessed for individual plant infrastructure and depends on the cement type

### **Conditions, barriers and constraints**

#### Technical

- ❖ Further experimental investigations using indigenous materials and Indian test procedures would be required to generate enough data to enable formulation of national standard

#### Policy

- ❖ Government funding for R&D of composite cement is required. Based on the results, Indian Standards must be developed using European standards as guidelines

#### Financial

- ❖ Possibility of high capital expenditure (capex)

## Annexure I: Glossary of terms

ACC	Air Cooled Condensers	LOI	loss on ignition
ACWP	Auxiliary Cooling Water Pump	LR t	Lime Reactivity
AFBCS	Atmospheric Fluidized Bed Combustion System	MT	million tonnes
AFR	alternative fuel and raw materials	MCC	Motor Control Centers
BFP	Boiler Feed Pump	MSW	Municipal Solid Waste
Capex	capital expenditure	MTPA	million tonnes per annum
CCBM	Closed Circuit Ball Mill	MW	megawatt
CDM	Clean Development Mechanism	opex	operating expenditure
CEMS	Continuous Emission Monitoring Systems	OPC	Ordinary Portland Cement
CFBCS	Circulating Fluidized Bed Combustion System	PPC	Portland Pozzolana Cement
CFD	Computational Fluid Dynamics	PSC	Portland Slag Cement
cl	clinker	RE	Renewable Energy
CEP	Condensate Extraction Pump	tCO <sub>2</sub> e	tonnes of CO <sub>2</sub> equivalent
CWP	Cooling Water Pump	tpd	tonnes per day
EMS	Energy Management Systems	tph	tonnes per hour
ESP	Electrostatic Precipitator	TR	tonne of refrigeration
FAKS	Fluidized Bed Advanced Cement Kiln System	TSR	Thermal Substitution Rate
FRP	Fiber Reinforced Plastic	VAM	Vapor Absorption Machine
GJ	gigajoules	VFD	Variable Frequency Drives
GBFS	Ground Blast Furnace Slag	VRM	Vertical Roller Mill
Gol	Government of India		
HPGR	High Pressure Grinding Rolls		
INR	Indian Rupee		
kcal	kilo calories		
kWh	kilowatt hours		
LED	Light Emitting Diode		



## Annexure II: Definition of Reference, Best Available Technology (BAT) and Target plants

Sl no	Parameter	Unit	Reference Plant	BAT Plant	Target Plant
1	Clinker Capacity	mMTPA	1.5	1.5	1.5
2	Cement Capacity	mMTPA	2.10	2.30	2.70
3	Kiln capacity	tpd	4,500	4,500	4,500
4	Kiln type		Modern, dry, precalciner preheater	Modern, dry, precalciner preheater	Modern, dry, precalciner preheater
5	No of stages in preheater		5	6	6 or 7
6	Single string / Double string		Single	Single	Single
7	Type of cooler		Reciprocating Grate Cooler	Latest generation cooler	Latest generation cooler
8	Raw meal to clinker factor		1.5	1.5	1.5
9	Specific thermal energy consumption	kcal/kg clinker	715	685	680
10	Specific thermal energy consumption	MJ/Mt clinker	2,990	2,865	2,846
11	Clinker factor	ratio	0.72	0.65	0.58
12	Specific power consumption	kWh/ Mt Cement	75	69.5	69.5
12.1	Raw mill	kWh/ Mt Cement	16	15.5	15.5
12.2	Coal mill	kWh/ Mt Cement	5	5	5
12.3	Pyro processing	kWh/ Mt Cement	24	21	21
12.4	Up to clinkerisation	kWh/ Mt Cement	45	41.5	41.5
12.5	Cement grinding	kWh/ Mt Cement	30	28	28
13	AFR Usage	TSR %	1	5	25.3
14	Cost of Electricity	INR/kWh	4.5	5	6
15	Fuel cost for cement kiln	INR/MkCal	800	900	1,000
16	Gross CO <sub>2</sub> emission per Mt cementitious product	kg CO <sub>2</sub> /Mt cementitious product	720	665	560

Reference plant has been considered as the average of top 20 percentile of Indian cement industry. Considering the fact that more than 50% of Indian cement industry capacity is less than 10 years old and all recent plants had high levels of energy efficiency practices incorporated, this reference plant has been considered for all emission reduction estimates in technology papers. BAT plant indicates the best-in-class in the Indian industry today. Industry, as a whole may achieve these average numbers by the year 2020. Target plant incorporates all wish list ideas and practices and could depict the average performance of the Indian cement industry by the year 2035.



Cement Sustainability Initiative (CSI), a member-led program of the World Business Council for Sustainable Development (WBCSD)

**'CSI members in India'**



**HEIDELBERGCEMENT**



**JANUARY 2013**