Good Practices Manual

Green House Gases Emission Reduction

Cement Sector

Prepared by

National Productivity Council

Supported by

Department of Industry and Policy Promotion

Prepared by

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PREFACE

It is now widely accepted that we have to limit the temperature rise to $2^{o}C$ to mitigate effects of climate change. This requires changing the portfolio of energy basket from fossils to non-renewable energy, reduce energy use through energy efficiency and conservation and reduce GHG emissions.

The broad intent and its goals can only be achieved by co-ordinated actions at various level by society, business, industry and government. As part of its endeavor the Government of India is formulating policies, action plans to support and guide industry and entrusted National Productivity Council to prepare of Best Practices Manual for Reducing GHG Emissions in various sectors namely, **Thermal Power Plant, Chlor Alkali, Cement, Pulp and Paper and Iron and Steel**.

This manual is expected to serve as reference manual for

- Identifying sources of GHG emissions
- Assess and quantify emissions.
- Evaluate and assess potential to improve energy efficiency and reduce GHG emissions.
- Propose a menu of options which industry can consider for assessment and implementation.

The scope of this manual covers GHG emissions in the plant boundary and does not include transportation of raw materials, products and wastes to secured landfills, emissions from domestic waste treatment and emissions from sales and other offices.

It is hoped the manual will be handy reference and guide for all levels of engineers and managers working in the sector.

STUDY TEAM

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1. INTRODUCTION

1.1 BACKGROUND

Energy is a major driver of economy and the per capita consumption of energy is a lead indicator of its development. The fossil fuels, constituting 72.4% of the energy basket as of 2013[1], is the major contributor of GHG emissions and consequently global warming. The wider consensus that the temperature rise is to be limited to 2^{o}C requires reducing GHG emissions by changing the portfolio of energy mix from fossil fuels to non-renewable sources, and reducing energy use through energy efficiency and conservation.

India is a net energy importing country and its GDP growth is one of the highest in the world. To maintain its growth rate as well as to ensure energy security and meet its committed GHG emission target reduction (30-35%) by 2030 from 2005 levels, India has been taking measures to shift its energy consumption towards renewable energy, besides adopting energy conservation and management measures. Studies indicate potential to reduce GHG emissions as shown in Figure 1.

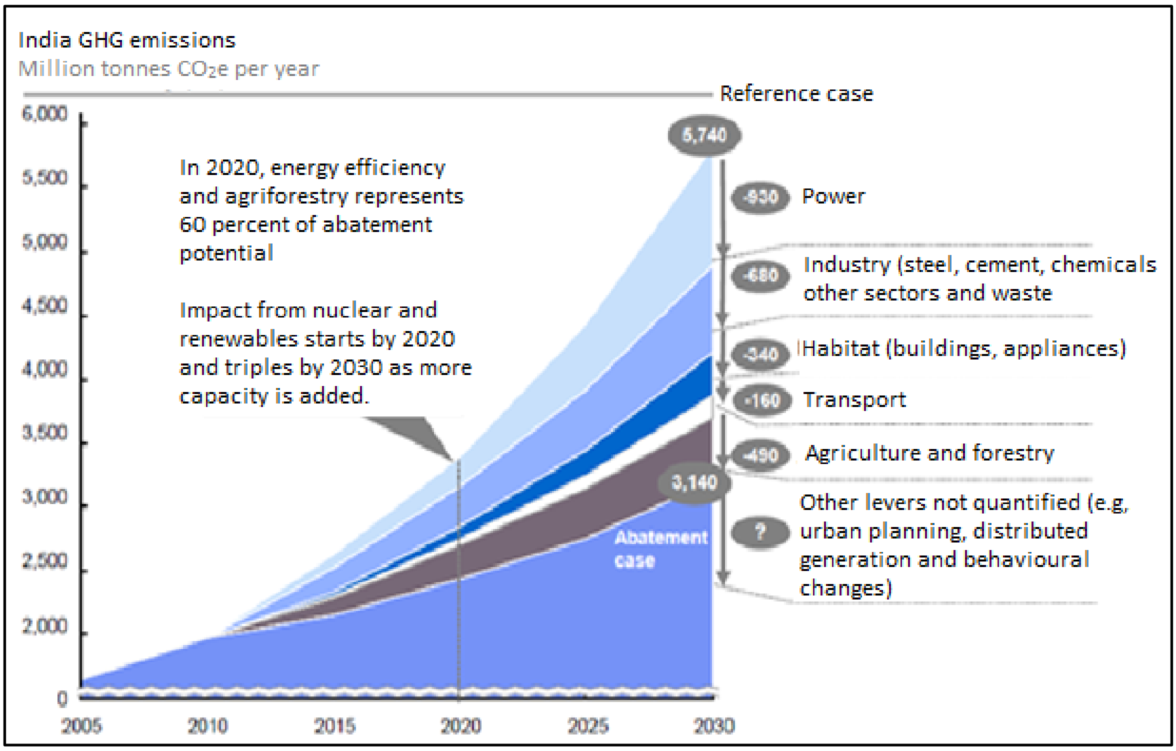


Figure 1 Indian GHG Emission Scenario (Past, Current & Projected)

Source: Pathways to lowcarbon_economy_Version2

[1]http://data.worldbank.org/indicator/EG.USE.COMM.FO.ZS

As can be seen, industrial sector's GHG reduction potential is about 680 million tonnes CO_2e per year. In line with these projections provided by various studies, Government of India has evolved policies, action plans and mission oriented programs to address the following objectives and issues.

- Energy security – to meet present and future needs
- Environmental impact-to address local emissions & global climate change
- Economic development – to create a sustainable development
- Ease of implementation

1.2 ABOUT THE PROJECT

To ensure effective translation of policy and implementation of action plans, Department of Industrial Policy & Promotion (DIPP), under Ministry of Commerce & Industry, Government of India has entrusted National Productivity Council of India (NPC) with the project titled "Preparation of Good Practices Manuals for Green House Gas Emission Reduction in Five Energy Intensive Industry Sectors in India" under the 12th Plan period (2012-2017).

The scope of the project is to conduct field and questionnaire survey in five selected energy intensive sectors (Thermal Power Plant, Chlor Alkali, Cement, Pulp and Paper and Iron and Steel) of Indian economy, and bringing out manuals on Good Practices for GHG Emission reduction in the selected energy intensive sectors. Out of these five energy intensive sectors, this manual highlights the best practices involved for reducing Green House Gases Emission Reduction in the cement sector.

This manual brings out sources and trends driving India's greenhouse gas emissions in the cement sector, outlining present situation and technologies that offer potential for significant emission reductions through enhanced energy efficiency that will put India on a sustained low-carbon path without sacrificing economic growth. It also highlights the Government of India policies and interventions that spur energy efficiency and GHG reduction activities in the sector eventually leading to improving energy security.

1.3 METHODOLOGY

For preparing this manual, the following methodology was adopted:

- Sector reports were prepared with inputs from questionnaire survey, detailed field visits and audits, workshops and guidance from steering committee.

- The synopses of the reports were extracted to prepare this manual for comprehensive presentation of information and provide guidelines for implementation of GHG emission reduction options.
- Feedback on the manual contents and the material was sought and received from industries, sector association, and other stakeholders and the same was incorporated in the final manual

1.4 GREENHOUSE GASES AND ITS IMPACT

Over the last 100 years, it has been found out that the earth is getting warmer and warmer, unlike previous 8000 years when temperatures have been relatively constant. The present temperature is 0.3–0.6 °C warmer than it was 100 years ago. The key greenhouse gas (GHG) causing global warming through human enhanced GHG effect is carbon dioxide.

The natural greenhouse effect is the process by which radiation from the earth's atmosphere warms its surface to a temperature above what it would be without its greenhouse gases naturally present in the atmosphere. The greenhouse gases naturally present in the atmosphere include carbon dioxide, water vapor, methane, nitrous oxide, and ozone.

Certain human activities add to the levels of most of the naturally occurring gases. For example, carbon dioxide is released to the atmosphere when fossil fuels such as oil, natural gas, coal, wood etc are burned. The enhanced greenhouse gas effect is the further rise in average earth's temperature due to increase in the amount of carbon dioxide and other greenhouse gases in the earth's atmosphere due to human activities. Both these effects are depicted in Figure 2.

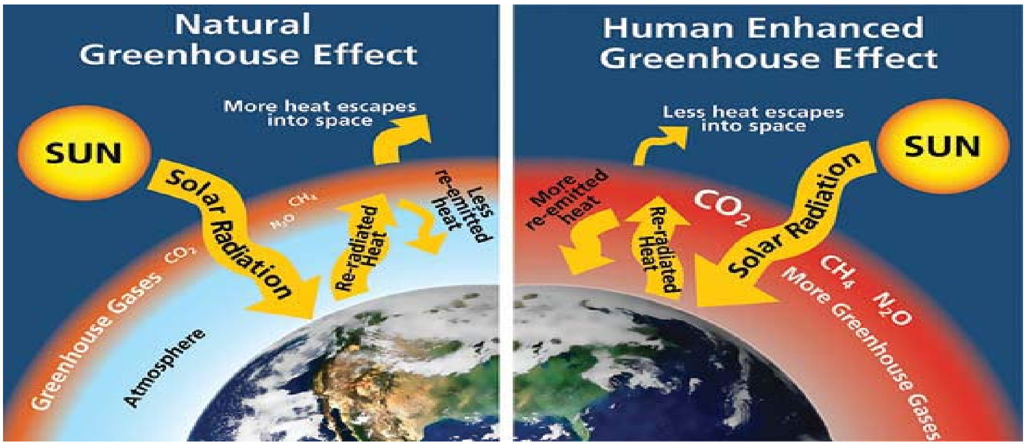


Figure 2 Natural and Human Enhanced Greenhouse Effect

Green House Gases (GHG) is of two types namely direct and indirect. Direct GHG contribute directly to the greenhouse effect in the atmosphere by trapping the infrared radiation near the earth's surface. The major GHG gases identified by Intergovernmental Panel on Climatic

Change (IPCC) are carbon dioxide, methane, nitrous oxide, hydrogen fluorocarbons, per fluorocarbons, sulphur hexafluoride.

Indirect GHG control the oxidising capacity of the troposphere by reducing the hydroxyl radical distribution thereby increasing the residence time of direct greenhouse gases, such as methane and ozone. Although there are a number of ways of measuring the strength of different greenhouse gases in the atmosphere, the Global Warming Potential (GWP) is the most used indicator.

GWP depends upon the greenhouse gas ability to absorb heat in the atmosphere. HFCs and PFCs are the most heat-absorbent. Methane traps over 21 times more heat per molecule than carbon dioxide, and nitrous oxide absorbs 270 times more heat per molecule than carbon dioxide. The GWPs for different GHGs are presented in Table 1.

Table 1 Direct and Indirect Green House Gases and its GWP

GHG	Name	Common Sources	Atmospheric Lifetime (years)*	Global Warming Potential
CO_2	Carbon Dioxide	Fossil fuel combustion, forest clearing, cement production etc.	50-200	1
CH_4	Methane	Landfills, production and distribution of natural gas and petroleum, fermentation from the digestive system of livestock, rice cultivation, fossil fuel combustion, etc.	12	21
N_2O	Nitrous Oxide	Fossil fuel combustion, fertilizers, nylon production, manure, etc.	150	310
HFC's	Hydro fluorocarbons	Refrigeration gases, aluminum smelting, semiconductor manufacturing, etc.	264	Up to 11,700
PFC's	Per fluorocarbons	Aluminum production, semiconductor industry, etc.	10,000	Up to 9200
H_2	Hydrogen	Chloro alkali production etc	100	5.8

The Figure 3 shows comparison of per capita CO_2 emission for the top five GHG emitting countries of the world and EU. India—owing to higher population—per capita CO_2 emission is the least. However, in terms of absolute emissions India is the third largest CO_2 emitting country, behind the US and China (2015) and contributing about 6 % (2.3 Gt CO_2) of global emissions (WEO 2015).

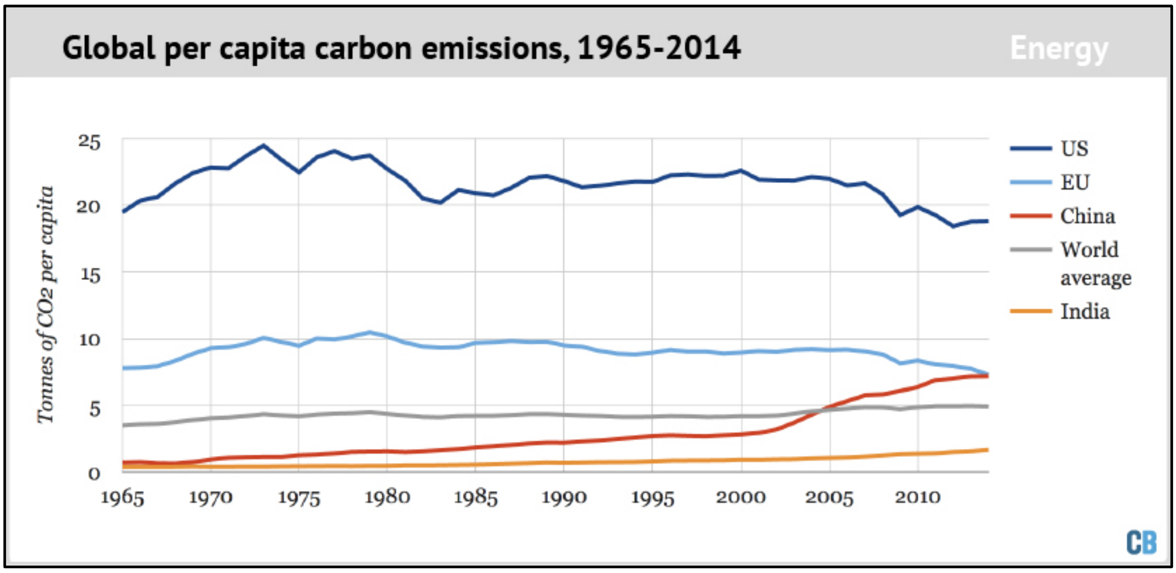


Figure 3 Per capita CO_2 Emissions

Impacts of Global Warming

Rise in Global Temperature

Observations show that global temperatures have risen by about 0.6 °C over the 20th century. There is strong evidence now that most of the observed warming over the last 50 years is caused by human activities. The various climate models predict that the global temperature will rise by about 6 °C by the year 2100.

Rise in Sea Level

In general, the faster the climatic change, the greater will be the risk of damage. The mean sea level is expected to rise 9–88 cm by the year 2100, causing flooding of low lying areas and other damages.

Food Shortages and Hunger

Water resources will be affected as precipitation and evaporation patterns change around the world. This will affect agricultural output. Food security is likely to be threatened and some regions are likely to experience severe food shortages and hunger.

Models also predict an average increase in temperature in India of 2.3–4.8°C for the benchmark doubling of carbon dioxide scenario. It is estimated that 7 million people would be displaced, 5700 km^2 of land and 4200 km of road would be lost, and wheat yields could decrease significantly.

Due to rising energy demand, India's CO_2 emissions are expected to grow at the rate of 7% and surpass the present EU-28 emissions by 2020. As a part of mitigation effort, India is committed to increase its share of non-fossil energy sources from current 19% to 40% by 2030. However, combustion of fossil fuel will continue to be the single major contributor to the global warming in the coming years and hence the focus is on efforts to opt for renewable energy and enhance energy efficiency.

1.5 OUTLINE OF ENERGY SCENARIO IN INDIA

The energy mix of India for 2013 presented in the pie chart (Figure 4) indicates fossil fuel is the main stay of India's energy mix.

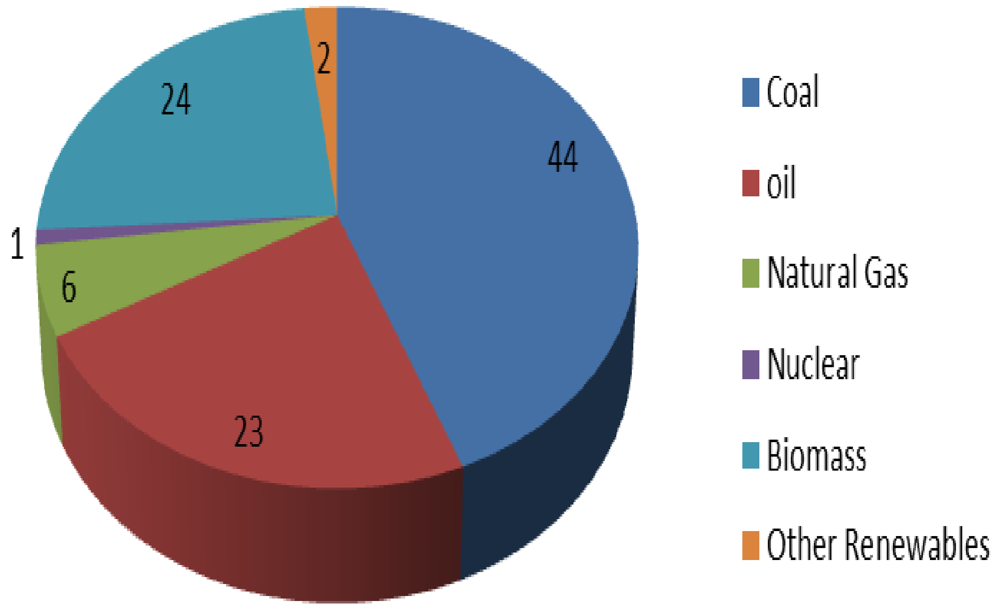


Figure 4 Primary Energy Demand in India for 775 MTOE

(Source : IEA, 2015)

Industrial energy demand has almost doubled over the 2000-2013 period, with strong growth from coal and electricity. Large expansion in the energy-intensive sectors is anticipated in the future. The present energy consumption in these energy intensive sectors in the country is high compared to the developed world. The major energy consuming sectors in the country are Iron & Steel, Chemicals, Textiles, Aluminium, Fertilizers, Cement & Paper. These sectors account for about 60% of the total energy consumption in industry. The energy consumption in manufacturing is relatively high in India which is reflected in the Specific Energy Consumption (SEC). This, therefore, provides an opportunity to reduce energy consumption and thereby GHG emissions. The typical SECs in different manufacturing sectors is presented in Table 2.

Table 2 Specific Energy consumption in Energy Intensive Industries

Sl. No.	Industrial Sector	Specific Energy Consumption (SEC)	
		India	World
1	Iron and Steel	6.5–7.0 GCal/Ton	4.5–5.5 GCal/Ton
2	Cement	80 kWh/T	110 kWh/T
3	Aluminium	4300 kWh/T (Refinery) 16500 kWh/T (Smelter)	3850 kWh/T (Refinery) 15250 kWh/T (Smelter)
4	Fertilizer	7.7 GCal/T of Urea	6.5 GCal/T of Urea
5	Paper and Pulp	8.4 Steam consumption/Ton	4.5 Steam consumption/Ton
6	Textile	7.1 GCal/Ton	3.1 GCal/Ton
7	Chlor Alkali	3.1 GCal/T (Soda ash) 2.1 GCal/T (Caustic Soda)	2.6 GCal/T (Soda ash) 1.8 GCal/T (Caustic Soda)

Source: BEE PAT Document

Energy Conservation and GHG Emission Reduction Initiatives by Government

The major policies that are currently promulgated and being implemented to meet the energy and climate challenge are summarized in Table 3.

Table 3 Government Policies and Initiatives for Energy Conservation

Policy /Initiative Statement	Key Features of the Policy
Energy Policies	
1. National Electricity Policy 2. National Rural Electrification Policy	• Access to Electricity - Available for all households in next five years • Availability of Power - Demand to be fully met by 2012. Energy and peaking shortages to be overcome and adequate spinning reserve to be available. • Supply of Reliable and Quality Power of specified standards in an efficient manner and at reasonable rates. • Per capita availability of electricity to be increased to over 1000 units.
3. National Tariff Policy 2006	• Minimum lifeline consumption of 1 unit/household/day. • Financial turnaround and commercial viability of electricity Sector. • Protection of consumers' interests.

Policy /Initiative Statement	Key Features of the Policy
Industrial Energy Efficiency Programs	
1. National Mission for Enhanced Energy Efficiency (NMEEE) (a) Market Transformation for Energy Efficiency (MTEE) (b) Energy Efficiency Financing Platform (EEFP) (c) Perform, Achieve, and Trade (PAT) Mechanism for Energy Efficiency	• Market-based approaches to unlock energy efficiency opportunities, estimated to be about Rs. 74,000 crores (2014-15) • Annual fuel savings in excess of 23 million toe • Cumulative avoided electricity capacity addition of 19,000 MW • CO_2 emission mitigation of 98 million tons per year
2. National Mission on Sustainable Habitat (NMSH)	Works on Municipal Solid Wastes, urban storm water & water mgmt. & energy efficiency
3. Energy efficiency Standards and Labelling Program	• BIS: formulations and implementations of national standards/production, quality and EMS certifications BEE : key thrust of EC Act, 2001
1. Capacity Building for Industrial Pollution Management	• Build capacity at the State and Central level, and develop a framework to address these issues in a comprehensive and systemic manner under an area-wide management approach. • The proposed project is aligned with the endeavour of the GoI to establish a National Program for Rehabilitation of Polluted Sites (NPRPS) as a framework for scaling up clean-up and rehabilitation of polluted sites and facilitate the reduction of environmental and health risks associated with legacy polluted sites.
Capping, Trading and Taxing	
1. Tax on Coal to Fund Clean Energy	All means to instil price signals to spur energy efficiency and using cleaner fuels

Policy /Initiative Statement	Key Features of the Policy
2. Renewable portfolio standards/obligation • Renewable Purchase Obligation (RPO) under the Electricity Act 2003 is mandated at the state level (discussed below in "National Policies Implemented at the State Level")	• States can choose to apply the RPS requirement to all its utilities or only the investor owned utilities. • States can also define what technologies are eligible to count towards the RPS requirements.
3. RECS (Renewable Energy certificate System)	• Aimed at addressing the mismatch between availability of RE resources in state and the requirement of the obligated entities to meet the renewable purchase obligation (RPO) • Cost of electricity generation from renewable energy sources is classified as cost of electricity generation equivalent to conventional energy sources and the cost for environmental attributes. • Two categories of certificates, viz., solar certificates issued to eligible entities for generation of electricity based on solar as renewable Cost of Electricity Generation by Renewable Sources Cost Equivalent to Conventional Source Cost for Environmental Attributes energy source, and non-solar certificates issued to eligible entities for generation of electricity based on renewable energy sources other than solar
Subsidies for Energy Conservation	
1. Financial incentives through the Jawaharlal Nehru National Solar Mission	• Creating capacity in the area of solar, wind, bio-mass and other forms of renewal energy generation • Supports financially as well as technically to promote solar heater other solar applications widely in the country and particularly in the areas where conventional energy is not possible to supply • Long term energy security • Ecologically sustainable growth • Set target-20,000MW
2. Financial incentives by the Ministry of New and Renewable Energy through the Indian Renewable Energy Development Agency	

Policy /Initiative Statement	Key Features of the Policy
Energy Conservation in Buildings and Municipalities	
Energy Conservation Building Code	• Provide technical support to BEE to implement the ECBC in a rigorous manner • Develop reference material and documentation to support the Code • Develop ECBC Training material for workshops and training programs • Develop a road map for ECBC implementation
1. Municipal Demand-Side Management 2. State Energy Conservation Fund	Municipal Demand Side Management (MuDSM) is devised to take care of the most common and other issues which are seen as a hurdle by the Municipality to shift itself towards the energy efficient zone from the existing situation of high amount of energy consumption.
Energy Conservation in Agriculture and Forestry Activities	
Agriculture, forestry, and other land use policies 1. Agricultural Demand - Side Management (AgDSM) 2. National Mission for Sustainable Agriculture 3. National Mission for a Green India	• Consists of those activities, methodologies, awareness, policy and technologies that influence consumer (farmers) behaviour and changes their (farmers) consumption patterns. • The objective of the AgDSM programme is to reduce peak demand, shift the time during which electricity is consumed to off-peak hours and to reduce the total quantum of consumption.

1.6 GHG EMISSION FACTORS

The emission factors considered for calculations in this manual are tabulated in Table 4 (CEA, 2014).

Table 4 GHG Emission Factors

No.	Parameter	Units	Factor
1	Grid Electricity	T CO_2/MWh	0.82
2	CPP Electricity		
a)	Coal Fired	T CO_2/MWh	1.03
b)	Diesel Fired	T CO_2/MWh	0.62
c)	Gas Fired	T CO_2/MWh	0.49
3	Coal (Sub-bituminous)	kg CO_2/TJ	96100
4	Gas/ Diesel	kg CO_2/TJ	74100

Source :CO_2 database, CEA, Ver. 10, 2014, IPCC Guidelines, 2006

2. CEMENT SECTOR PROFILE

2.1 INTRODUCTION

The Indian cement industry is the second largest producer in the world accounting for about 6% of the World's cement production, with installed capacity of around 390 MTPA and annual production of 270 MTPA in 2014-15.

To meet the Govt. plans on development of highways, smart cities, affordable housing and other infrastructure, the projected demand for cement in 2019–2020 is 415 MTPA, implying installed capacity of at least 460 MTPA at 90% utilization. The Indian cement industry is expected to continue its fast-paced growth and attain installed capacity of 850 MTPA a by 2030 and 1350 MTPA by 2050.

There are 178 (DIPP, 2012) large cement plants accounting for 97% of the total installed capacity of the country with 365 small plants accounts for the list. Per-capita cement consumption in India is 190 kg which is much lower than the world's average of around 396kg. Average kiln capacity is currently 4500 TPD, with the largest kilns reaching a capacity of 13500 TPD. Small cement plants in India account for a small share of the total installed capacity (less than 5%).

Availability of fly-ash (from thermal power plants) and use of advance technology has increased production of blended cement. The environment-friendly blended cement is more cost-efficient to produce, as it requires lesser input of clinker and energy.

2.2 TYPES OF CEMENT PRODUCED IN INDIA

The different types of cement are manufacturing to cater various needs of the customers.

- Portland Blast Furnace slag cement
- Sulphate Resisting Portland cement
- Rapid Hardening Portland cement
- Ordinary Portland cement (OPC)
- Portland Pozzolana cement (PPC)
- Oil Well Cement
- Clinker Cement
- White Cement

Apart from these, some of the other types of cement available in India can also be classified as:

- Low heat cement
- High early strength cement
- Hydrophobic cement
- High aluminium cement
- Masonry cement

2.3 ENERGY CONSUMPTION OVERVIEW

Cement industry is an energy intensive industry and third largest coal consumer in the country after power and steel industry requiring both electrical & thermal energy for its operation.

Cement industry accounts for around 10% of the coal and 6% of the electricity consumed by the Indian industrial sector. Energy cost is considered as a major factor in pricing of the cement. On an average, cement plants spend about 35 – 50% of the total manufacturing cost of cement to meet their energy demands. Around 25% of the manufacturing cost is spent on raw materials for cement manufacturing. The rest of the cost is shared among the manpower and factory overheads. The cost break-up in cement manufacturing is shown in Figure 5.

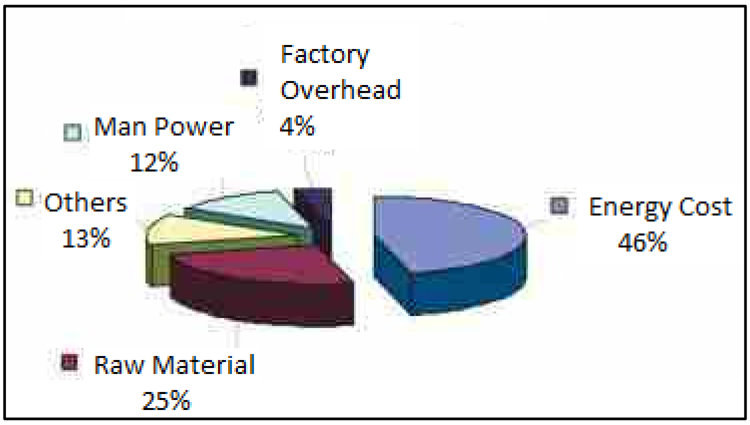


Figure 5 Break-up of Cement Manufacturing Costs

Cement manufacturing is an energy-intensive process. The kiln process consumes around 90 percent of the cement manufacturing energy. The remaining 10 percent is consumed in almost equal amounts by activities related to fuel and raw materials preparation, grinding of clinker and the blending of materials to prepare the finished cement product.

Electrical Energy

Modern cement plants on an average consume about 78 kWh[2] of electrical energy for producing one Ton of cement. Cement plant requires electrical energy to its mill drives (kiln, coal mill, cement mill), fans, conveyors, packers and for lighting systems. Kiln and mills are major electrical power consuming areas of the cement plant consuming about 60% of the total electrical energy requirement. For older cement plants, the energy consumption is normally in the range of 80-100 kW per Ton of cement. The typical section wise electrical energy consumption is shown in Figure 6

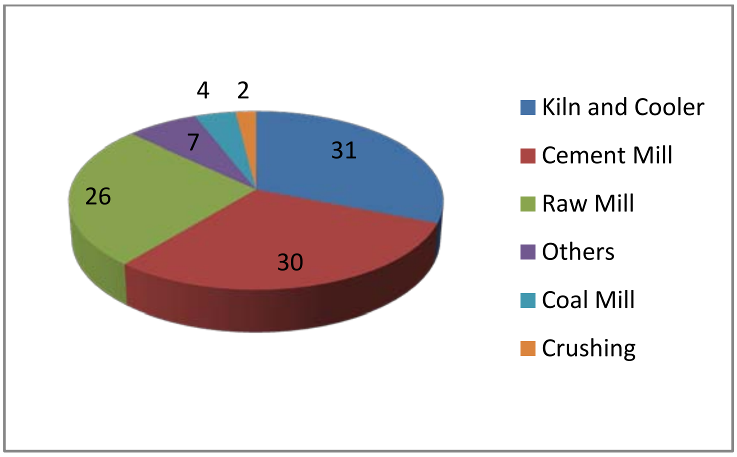


Figure 6 Break-up of Electrical Energy Consumption

Source: (CMA, 2015)

Thermal Energy

The cement industry relies heavily on carbon-intensive fossil fuels. Coal and petroleum coke products are mostly used as primary fuel to burn raw mix. Liquid petroleum products like HSD is used only during start-up of the kiln while tire-derived fuels, solid waste, liquid waste and other alternative energy sources are also being used to reduce the primary fuel i.e. coal consumption.

On an average, Indian cement plants requires 726 kcal/kg clinker of thermal energy for producing one kg of clinker. The major use of thermal energy is in the kiln and pre-calciner systems. Thermal energy is needed for the raw meal processing specifically for converting the raw mix to clinker. Pyro processing—conversion of raw meal to clinker— is the most energy concentrated stage in cement production. The number of stages in the pre-heater system has major bearing on the thermal energy consumption in kiln system. Continuous technological upgradation and assimilation of latest technologies have been steady increasing

[2] 14th NCB International Seminar on Cement and Building Materials

in the cement industry. Today 99% of the plans use dry process technology compared to 6% in 1960.

Indian cement industry has always been a trend setter for adopting the best available energy efficient technologies. The best thermal and electrical energy consumption presently achieved in India is 670 kcal/kg clinker and 68 kWh/T cement. The specific energy consumption of the Indian cement plants has been reducing with continuous up-gradation of technologies and the change in process technologies. The Table 5 shows the progressive reduction in specific energy consumption by Indian cement Industry (CII.2015).

Table 5 Heat and Power Consumption Trends

Parameters	Year				
	1950-60	**1970s**	**1980s**	**1990s**	**Post 2000**
Heat Consumption (kcal/kg clk)	1300-1600	900-1000	800-900	750-800	650-750
Power Consumption (kWh/MT cement)	115-130	110-125	105-115	95-105	80-100

Source : CII, 2015

2.4 VARIOUS SOURCES OF GHG EMISSIONS IN CEMENT SECTOR

About 30 to 40% of CO_2 emissions are produced by burning fossil fuels, mainly to reach the required high temperatures in the kiln and associated equipment. The remaining 10% of CO_2 emissions result from transportation and the generation of electricity necessary for other plant processes.

About 50 to 60% of cement production–related CO_2 emissions are generated during the decomposition of limestone and other calcareous material to produce clinker. Emissions related to clinker production are difficult to reduce because production of clinker (cement intermediary) is produced with calcination of lime that releases CO_2. The thermal energy required for calcination is provided by coal/lignite.

The various GHG emitting processes are as follows.

- The clinker production through calcination emits 525 kg CO_2 / t clinker (as per IPCC default value).

- Use of fossil fuel in the kiln for calcination of lime to cement clinker is one of the key energy input. The cement plants in India are operating with a thermal specific energy consumption (SEC) ranging between 658 – 1269 kcal/kg clinker. Based on data collected from 10 plants, the thermal SEC is around 767 kcal/kg clinker on average which translate into 308 kg CO_2 / t clinker based on emission factor of 0.402 kg CO_2 / kcal.

- The electricity consumption varies from 67 kWh/t cement for the best plant and over 100 kWh/t cement for older plants with inefficient technologies. The average power consumption is 73.6 kWh/t cement based on data received from 10 cement plants. This electrical input translates to 0.0604 t CO_2 / t cement.

- The overall GHG for ton of cement depends on clinker factor (i.e. fraction of clinker used in one unit of cement production). The following table details the GHG computation based on clinker factor of 0.75.

The GHG emission factors for energy use are given in Table 6.

Table 6 GHG Emission Factors

Calcination	kg CO_2/t clinker	525
	t CO_2/t cement	0.394
Thermal SEC	kcal/kg clinker	767
	kg CO_2/t clinker	309.868
	t CO_2/t cement	0.232
Electrical SEC	kWh/t cement	73.600
	t CO_2/t cement	0.0604
Total GHG	t CO_2/t cement	0.687
Energy related GHG	t CO_2/t cement	0.292
Proportion of CO2 from Energy use	%	43
Proportion of CO2 from calcination	%	57

As may be seen from Table 5, 687 kg CO_2/t cement on average is released out of which 57% is from calcination process and balance 43% is from use of energy. While CO_2 release from the process cannot be reduced directly as long as lime is used as the raw material, the use of alternate raw materials such as fly ash, petcoke etc would reduce quantity of clinker in cement (denoted by clinker factor) would result in reduced CO_2 contribution from the process in cement manufacturing. The SEC shows a wide variation indicating opprtunity for improving energy efficiency and use of alternate fuels in order to reduce GHG emissions from cement manufacturing.

2.5 PRODUCTIVITY ASPECTS AND INDICATORS IN CEMENT SECTOR

Productivity Indicators

Ratio of output to particular inputs may be termed as “partial productivity” measures. There are as many indices of partial productivity as there are factors of production. The most important and most often used are the partial productivity indices of labour and capital respective1y. These indices are:

$$AP_L = \frac{Q}{L}$$

$$AP_K = \frac{Q}{K}$$

Where,

APL and APK are average productivity of labour and capital

Q is the total output/value added

L is the labour

K is the capital.

While the partial productivity indices of labour and capital are simply the average product of labour and capital, the total factor productivity, often referred to as the index of “technical progress", is defined as output per unit of all factors of production combined. It is the composite measure of productivity which relates output to all the conventional inputs simultaneously. The concept of total factor productivity defined as the ratio between real product or output and real factor input (a weighted sum of the different inputs).

Labour and Capital Productivity

The term ‘Labour Productivity’ is generally defined as “the ratio of physical amount of output achieved in a given period to the corresponding amount of labour expended”. In any business organization wage payments are directly or indirectly based on the skill and productivity of the workers, therefore labour productivity is considered as the most important factors in productivity computations.

There are many methods to determine labour productivity. One simple method using the above definition is input in terms of cost/expenses and capacity and utilization and input in terms of man-hours.

Determinants of Labour Productivity Growth

Factors such as economies of scale, increasing capital labour ratio and increase in wage rate have considerable influence on labour productivity growth. Generally, more capital-intensive industries are more productive and efficient than the less capital intensive ones.

The productivity growth function is expressed as:

ln (APLG) = á + ln (CAPG) + ln (EMOLG) + ln (GVAG) + u (1)

Where,

APLG	= growth of labour productivity
CAPG	= growth of capital intensity
EMOLG	= growth of emoluments per employee
GVAG	= growth of gross value added
u	= error term

Labour productivity growth is regressed on growth of value added, capital labour ratio and emoluments per worker. A positive and significant relationship is expected between growth of labour productivity and value added. Growth in labour productivity can also be due to increase in capital intensity through the substitution of capital for labour or the availability of more machines per worker. Increase in growth of emoluments per worker could positively influence the productivity of labour, particularly where emoluments paid are very low.

Some suggestions for cost reduction and performance improvement and improving business effectiveness include,

- Control over operating expenses and cost of goods sold.
- Maximize capacity utilization to reduce overheads.
- Reduce interest burden and increasing own funds
- Use long-term funds to finance core current assets.
- Prefer plant location close to raw materials

PAT Targets for Cement Sector

Cement sector has been categorized on the basis of their product/process in to seven subsectors i.e. Portland Pozzolana Cement(PPC), Ordinary Portland Cement(OPC), Portland Slag Cement (PSC), Wet Plants, White Plants, Grinding Plants and only Clinkerization Plants. The total reported energy consumption of all the designated consumers put together is about 15.01 MTOE in the baseline year.

The threshold limit of 30000 TOE has been defined in PAT for cement sector, and 85 nos. of designated consumers have been identified out of total 148 cement plants existed during 2007-08.

PAT Target Status

By the end of the first PAT cycle, the energy savings of 0.816 MTOE /year is expected to be achieved, which is around 12% of total national energy saving targets assessed under PAT (BEE, 2012).

It is estimated that 3 Million tons of GHG equivalent emissions would be reduced at the end of PAT cycle-1.

However, since it is expected that the cumulative GHG reduction for all 85 cement plants of PAT cycle-1 would exceed 5 Million tonnes of CO_2 which is more than the PAT target, BEE has notified more cement plants as part of PAT cycle-2. The proposed target would be around 7% keeping in view India's commitment for GHG reduction through INDCs.

A sample of targets achieved by cement plants with their energy reduction and Equivalent GHG reduction as part of PAT cyle-1 is given in Table 7.

Table 7 Targets Assigned and Achieved

S. No	Name, Address and State	Target Specific Energy Consumption	Equivalent Major Product Output	Achieved Specific Energy Consumption	Achieved Energy reduction	Equivalent GHG Reduction
		TOE/ton of Product	tons	TOE/ton of Product	TOE	Tons of CO_2
Major Product Portland Pozzolana Cement (PPC) Plants						
1	Madras Cements Ltd , Alathiyur Work, Ariyalur, Tamil Nadu	0.0796	3195018.66	0.0768	8946.05	34417.25
2	Penna Cement Industries Ltd. Ganeshpahad, Nalgonda, Andhra Pradesh	0.0811	1291097.78	0.0793	2323.98	8940.80
3	Ambuja Cement Ltd. Ambujanagar, Gujarat	0.0815	5466373.46	0.0756	32251.60	124078.37
4	Kesoram Cement Basantnagar Karimnagar, Andhra Pradesh	0.0981	1521847.95	0.0814	25414.86	97776.05
	Major Product Ordinary Portland Cement (OPC) Plants					
5	The K C P Ltd., Cement unit- Macherla, Guntur, Andhra Pradesh	0.0924	749537.31	0.0919	374.77	1441.81
6	My Home Industries Ltd., Mellacheruvu, Nalgonda, Andhra Pradesh	0.0989	2510059.37	0.0987	502.01	1931.34
7	Vasavadatta Cement, Gulbaraga Sedam, Gulbaraga, Karnataka	0.1046	3730929.49	0.091	50740.64	195209.39
8	Penna Cement Industries Limited, Boyareddypalli, Anantapur, Andhra Pradesh	0.1047	1260383.26	0.0874	21804.63	83886.77
9	Rain cement Ltd Unit-II, Boinchervupally, Kurnool, Andhra Pradesh	0.1128	979298.65	0.0997	12828.81	49355.01
	Major Product Portland Slag Cement (PSC) Plants					
10	Penna Cement Industries Ltd., Talaricheruvu, Ananatpur, Andhra Pradesh	0.082	1792310.65	0.0706	20432.34	78607.30
Total					**175619.70**	**675644.10**

Renewable Purchase Obligation Targets for Cement Industry

Introduction of Renewable based electricity generation started in India in 1990s. While Government of India continues to promote Renewable power generation through various financial and fiscal instruments, the major shift has come from Renewable Purchase Obligation (RPO) incorporated in Electricity Act (EA) 2003. The Act lays responsibility on State Electricity Regulatory Commissions (SERCs) to specify percentage of Electricity to be purchased out of total electricity consumption within its area of distribution licensee.

The RPO targets and potential GHG reductions for cement industry is determined based on average specific electricity consumption and production. For the purpose of GHG reduction calculation all India grid emission factor of 0.82 t CO2/MWh is taken despite the plants use most of its electricity from CPPs with higher emission factor. The GHG reductions from RPO is 1.079 MT CO2 based on 2014-15 production as can be seen from Table 8.

Table 8 Target GHG Reduction from RPO

Parameter	Units	Value
Total Cement Production (2014-15)	MTPA	270
Average Electricity Consumption	kWh/Ton of Cement	73.6
Total Electricity Consumed	MUs	19872
RPO @ 6.62%	MUs	1315.17
Avg. all India Grid Emission Factor	Ton/MWh	0.82
Total GHG Reduction Targeted from RPO	T CO_2	1078732
Total GHG Reduction Targeted from RPO	MT CO_2	1.079

For cement sector, reliance on captive power is much more than grid power. The data from 10 cement plants studied indicates that out of their net electricity requirement (excluding WHR power), captive power constitutes 77% and grid power constitutes 23%. RPO targets and Achievements for 10 cement plants are given in Table 9.

Table 9 RPO Targets and Achievements

Parameter		Units	Value
Electricity Purchased from Grid		MUs	381.97
Electricity Consumed from CPP		MUs	1283.12
Electricity Consumed from WHR		MUs	8.52
Grid Power	RPO Target	MUs	25.29
	RPO Achievement	MUs	17.23
	GHG Target	T CO_2	20737.8
	GHG Achievement	T CO_2	14128.6
CPP Power	RPO Target	MUs	84.94
	RPO Achievement	MUs	0
	GHG Target	T CO_2	69650.8
	GHG Achievement	T CO_2	0
Total GHG Target (Grid + CPP)		T CO_2	90388.6
Total GHG Achievement (Grid + CPP)		T CO_2	14128.6
Difference in Target and Achievement		T CO_2	76260

Use of Alternate Fuels

Another significant action taken in the cement industry is the use of alternate fuels such as biomass, municipal solid wastes/refuse driven fuels, liquid waste from pharmaceutical, pet-coke. Many plants have made investments for this purpose mainly to ensure fuel availability and reduce cost, but achieved improved energy efficiency and reduced GHG emissions as well. The Table 10 provides details about energy contributed from alternate fuels and equivalent GHG reductions for 10 plants for which data has been collected.

Table 10 Reduction in GHG from use of Alternate Fuels

Plant Reference	Energy from Alternate Fuels	Equivalent GHG reductions (2014-15)
	Million kcal/year	T CO_2 per year
Vasavadatta Cements	119153.76	48092
Penna Cement, Ganeshpahad	0	0.00
Penna cement, Boyareddipalli	113603.995	45852
KCP cement, Macherla	1085.39	438
Ambuja Cement, Ambuja Nagar	1581122.527	638172
Rain Cements, Sreepuram	283221.257	114313

Plant Reference	Energy from Alternate Fuels	Equivalent GHG reductions (2014-15)
	Million kcal/year	T CO_2 per year
Penna Cement, Thalaricheruvu	0	0.00
Ramco Cement, Alathyur	287232.21	115932
KIL Cement, Basanth Nagar	6028.33	2433
My Home Cement, Mellacheruvu	29201.36	11786
Total		**977022**

Source: Energy from alternate fuels from cement plants, GHG calculations by authors

Use of Alterative Raw Materials

On the alternate raw materials front, use of fly ash is the single most measure that has resulted improved SEC for many cement plants in India. The use of fly ash has gone up to 35% in some cement plants.

The increased fly ash percentage in cement (PPC) would reduce clinker requirement thus, lower SEC/ton of cement. The use of fly ash also results in lower grinding energy in cement mills as it is easy to grind fly ash than clinker. The Table 11 provides details of expected GHG reductions when fly ash utilization increased from 23.4% to 31% (about 7% increases).

Table 11 Reduction in GHG Emissions by Increase in Fly Ash Utilisation

Parameters	UOM	GHG with Baseline % Fly Ash	GHG with Assessment % Fly Ash
Calcination	kg CO_2/t clinker	525	525
	t CO_2/t cement	0.381	0.341
Thermal SEC	kcal/kg clinker	767	767
	kg CO_2/t clinker	309.86	309.86
	t CO_2/t cement	0.225	0.201
Electrical SEC	kWh/t cement	73.6	73.6
	t CO_2/t cement	0.0604	0.0604
Total GHG	t CO_2/t cement	0.666	0.603
Reduction GHG emission	t CO_2/t cement	0.063	
PPC production from the plants during 2014-15	Tonnes/year	9377748	
Total GHG reduction due to increase in fly ash	t CO_2/t cement	595018	

Parameters	UOM	GHG with Baseline % Fly Ash	GHG with Assessment % Fly Ash
utilisation			
Energy related GHG	t CO_2/t cement	0.285	0.262
Proportion of CO_2 from Energy use	%	42.81	43.41
Proportion of CO_2 from calcination	%	57.19	56.59

Source: Fly ash & PPC production data from cement plants and calculations by authors.

As seen from the above data that when fly ash utilization increased by 7%, the GHG emissions are reduced by about 10%. Thus, making fly ash available to cement plants is one of the key factors in GHG reduction.

3. CEMENT MANUFACTURING PROCESS

3.1 OVERVIEW OF CEMENT PRODUCTION

Cement manufacturing involves mining of the raw material, crushing, pre-blending, raw material & coal grinding, pyro-processing, clinker grinding and cement packing. The raw materials required for cement manufacturing process are extracted through mining. The extracted material is crushed in primary and secondary crushers to get the required size for further processing. The crushed material is pre-blended and then is transported to grinding operations.

In grinding operation material is ground to the required fineness and sent to pyro-processing section for burning to form clinker. The clinker is transported to clinker grinding operation where it is ground with about 5% of gypsum to form cement.

The final product cement is stored in cement silos and then sent to packing plant. Cement is transported by rail/ road or by ship to various destinations.

A typical process flow sheet is given in Figure 7

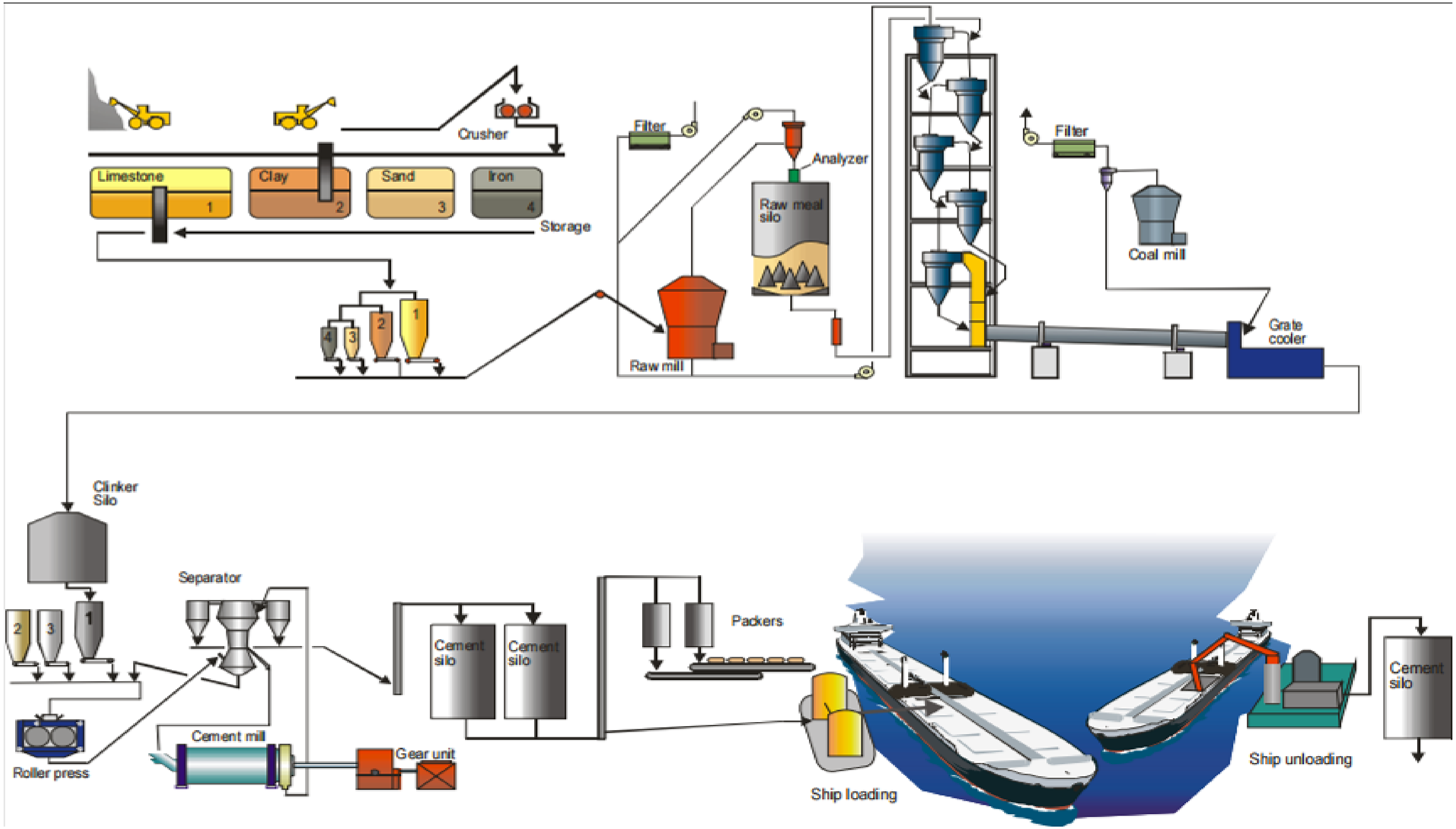


Figure 7 Process flow sheet of a typical Cement Plant

3.2 TYPES OF PROCESS

The main process prevalent in cement industry is dry process where the raw material is in dry powder form unlike older wet process where raw material is in slurry form. The main equipment in a cement plant is the rotary kiln where most of the reactions take place. The rotary kiln in dry process can be of the following types:

- The long dry process rotary kiln without internal installation.
- The long dry process rotary kiln with internal heat exchangers, such as chains, refractory bridges, etc.,
- The short dry process rotary kiln working in conjunction with pre-heaters, such as suspension pre-heaters or lepol kiln.
- The dry process rotary kiln with waste heat boiler.

From Table 12**,** it can be seen that earlier long wet process /dry process kilns the capacity was 0.45-0.8 TPD/m^3 where as the latest short pre-heater/pre-calciner kilns the capacities are > 3.5 TPD/m^3.

Wet process kilns consumes around 1300-1650 kcal/kg clinker when compared to dry process kiln where thermal energy is around 700-850 kcal/kg clinker thereby gaining a net savings on fuel combustion and thereby reduction in CO_2 generation.

Table 12 Comparison of Different Kiln Systems

KILN SYSTEMS	RPM	TPD/m^3	L/D	kcal/kg	kWh/t	Residence time, min	Kiln system exit T, °C	ΔP, MM H_2O	Exit gas, NM^3/KG CLINKER
LONG WET	1	0.45- 0.8	30-35	1300-1650	17-25	180-240	150-230	150-180	3.4
LONG DRY	1	0.5-0.8	30-35	1100-1300	20-30	180-240	380-400	150-200	1.8
LEPOL	1.5	1.5-2.2	12-15	950-1200	20-25	30	100-120	250-400	2.0
CYCLONE PREHEATER	2.0	1.5-2.2	14-16	750-900	25	30-40	350	500-700	1.5
PRE-CALCINER	3.6- 5.0	3.5-5.0	14-16	700-850	25	20-30	280-360	500-700	1.4

3.3 RAW MATERIALS

Raw material required for cement manufacturing are calcareous materials (source of lime) mostly limestone and argillaceous materials (source of silica, alumina and iron oxide) mostly clay or shale. The raw materials (raw mix) are heated using coal in the kiln to a high temperature and coal ash is absorbed by the clinker and becomes one of the raw materials.

3.4 CRUSHING

Cement raw materials blasted in the quarry are reduced in size for further processing. The size reduction is carried out in crushers and grinding mills. Crushing is size reduction in coarse range whereas grinding refers to size reduction in fine range. Crushers are used to reduce the particle size from 1200 mm to about 80 / 20mm. The crushing may be completed in one or more stages. The following equipment for size reduction in coarse range are used:

- Jaw crushers
- Gyratory crushers
- Roll crushers

3.5 PRE-HOMOGENISATION

Pre-homogenisation of raw materials— for limestone and clay— is carried out in cases where the raw material chemical composition varies greatly. With the increasing variation in the grades of coal used for coal firing installations, there is a growing need for pre-homogenisation and storage of coal. Stacker and Reclaimer systems are used for both pre-homogenisation and buffer storage and designed for heavy-duty operations. The stackers and reclaimers are controlled by state-of-the-art PLC-based technology designed for fully automatic operation.

3.6 GRINDING

Grinding mills are used for raw material, coal and clinker grinding. About 75% of the plant electrical energy is consumed by grinding operation alone. The types of grinding mill are of the following:

- Ball Mill
- Vertical Roller Mill
- Roller Press

Ball Mills

Ball or tube mills are horizontally rotating steel cylinders where size reduction of the mill feed is performed by motion of the grinding media. Rotation of the mill cylinder raises the pile of mill feed and grinding media to an optimum height, necessary for grinding operation. Grinding is performed by impact and friction between the grinding balls which hit one against another, as well as between the grinding media and the mill lining itself. Ball mill circuits for raw meal, coal and clinker grinding are of the following types:

- Open circuit
- Closed circuit
- Air swept

Open circuit
The material to be ground passes once through the ball mill. Open circuit mills are used only in cement grinding. Open circuit mill is used for cement grinding.

Closed circuit
The material discharge from the mill is separated by classifying into fines and coarse particles. The fines are taken out as product and the course is being return to the ball mill for further reduction. Closed circuit mill is used for raw material grinding.

Air swept
In air swept ball mill the air/gas velocity is kept high enough to extract ground material from the mill. The extracted material is separated in dust collectors. Air swept mill is used for coal grinding.

Vertical Roller Mills

The Vertical Roller mills use pressure and shear generated between the rollers and the rotating table to crush and grind materials. Feed material is directed on to the grinding table by the feed chute. The rotation of the grinding table accelerates the material towards the grinding track and passes it under the rollers.

Partially ground material passes over into the hot gas stream and the moisture in the materials is evaporated almost immediately while the finer portion of material is carried by the gas stream to a separator. The separator allows material that has reached the required fineness to leave the mill, while it rejects oversized material and sends it back to the table for further grinding.

Vertical Roller Mill (VRM) for Coal Grinding

Air-swept vertical roller mill is widely used for coal grinding installations. It can dry all types of coal, while providing excellent economy in terms of specific energy consumption. Equipped with the high-efficiency dynamic separator, the VRM coal mill will grind any type of coal to the required fineness at the highest efficiency. When provided with a variable speed mill motor, the VRM will also grind pet coke and anthracite down to fineness below 5% +90 μm.

Vertical Roller Mill for Raw Meal Preparation

The operating principle for raw meal grinding is similar to that coal grinding. The features are the following:

- From very easy-to-grind to very hard-to-grind material – roughly from less than 3 kWh/t to more than 11 kWh/t.
- From less than 1% moisture to more than 20% moisture in feed material
- From non-abrasive to very abrasive materials.
- From non-sticky to very sticky feed material.

Fan System

There are a number of arrangements for raw material grinding systems involving vertical roller mills. However the most common solution today is the so called three-fan system. The three-fan system provides the best operational control with less interaction between operation of mill and kiln respectively.

The three-fan system uses cyclones to de-dust the mill vent gas. This arrangement reduces the operating suction and usually also the gas volume for the filter, which may be either electrostatic precipitator or bag house filter.

As the mill requires significantly more gas than supplied by the kiln, a certain part of the gas flow is guided from the mill fan through the recirculation duct back to the mill.
The raw material feeding system is equipped with a magnet separator and metal detector for protection of the mill parts. In case the raw material is significantly contaminated with metal, an optional secondary refinery system can be adopted.

OK Vertical Roller Mill for Cement Grinding

The OK series is the premier roller mill for finish grinding of Portland cement, slag, and blended cements. Vertical roller mills use 30-50% less energy than ball mill systems. It has low footprint and reduces civil construction costs. Excellent drying makes the mill well suited for grinding blast furnace slag or blended cements from one or more wet components.

Table 13 shows the electrical energy saving potential when VRM is used over a conventional ball mill when cement is ground.

Table 13 SEC for VRM and Ball Mills

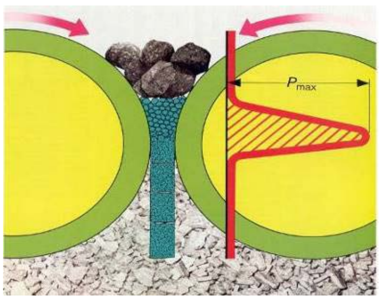
Specific Energy Consumption (kWh/t)								
	Portland Cement				Slag*			
	3300		4000		4000		5000	
	OK Mill	Ball Mill	OK Mill	Ball Mill	OK Mill	Ball Mill	OK Mill	Ball Mill
Mill	17.6	34.2	21.3	44.9	25.7	51.8	32.2	71.1
Fan etc.	6.9	3.2	8.3	4.9	9.4	7.6	13	12.3
Total	**24.5**	**37.4**	**29.6**	**49.8**	**35.1**	**59.4**	**45.2**	**83.4**
***Slag with 8% moisture**								

Source :(FLS Brochures)

Roller Press

In roller press (Figure 8), comminution of the material is effected under extremely high pressure in the gap between two contra rotating rollers. The material fed in between two rollers is completely fractioned and leaves the pair of rolls as a tightly packed cake. Roller presses are normally used particularly in upgrading the existing ball mill circuits either to increase production or to reduce specific power consumption.

High-pressure roller grinding of cement clinker and hard brittle materials is a modern and very energy-efficient process.



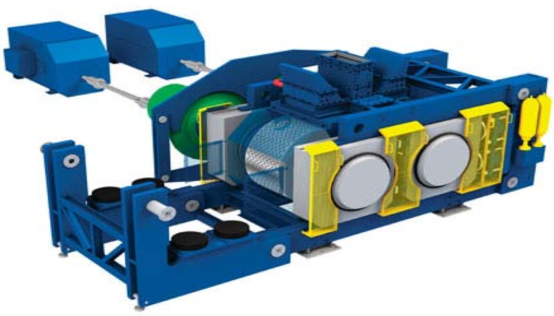


Figure 8 Roller Press

Separators

In the closed circuit operation, separators are used to separate the fine particles to qualify as “finished product” from the coarser particles (oversize) in the product discharged from the grinding mill. In the dry system of closed-circuit grinding the separation is effected in devices called as the air separator.

Types of Separators

- Static air separator
- Dynamic air separator
- Cyclone air separator
- High efficiency Separators

3.7 PYROPROCESSING

In pyro process, the raw mix is burnt to about 1450^{0}C in the kiln to form clinker, which passes through the grade cooler. The outlet temperature of clinker is around 70-100^{0}C.

The Figure 9 shows the pyro processing comprising pre-heater, pre-calciner, kiln and cooling system.

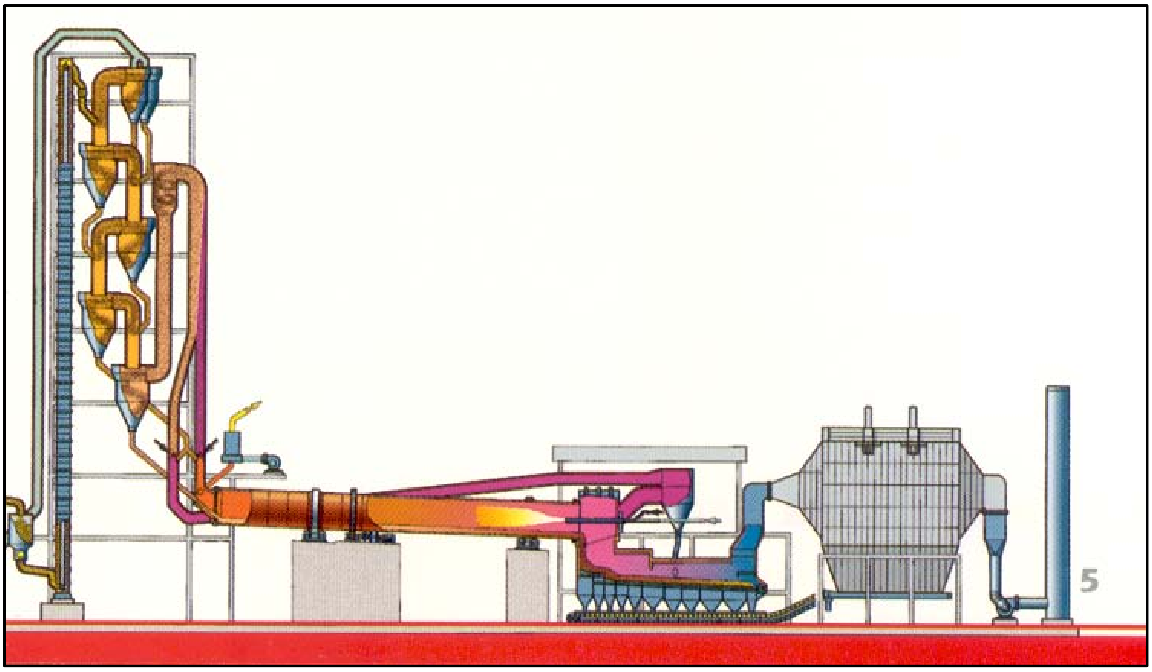


Figure 9 Pre-heater, Pre-Calciner, Kiln and Cooler System

Dry Process Kiln System

In modern cement plants, raw meal is preheated to calcination temperature in a multi-stage cyclone preheater and most of the calcination process takes place in a separately fired calciner. The remaining calcination and clinkerization process takes place in a short length-to-diameter rotary kiln without internals.

In pre calcination kilns calcining of the raw mix is performed separately in a calciner. The supply of fuel is divided between two firing units one burner in kiln and the other in suspension preheater. The combustion air for pre-calciner is drawn through separate duct from cooler.

There are different types of pre-heater / pre-calcinator systems available like 4 stage and 5 stage with inline calciner or separate line calciner of FLS system.

The advantages of 6 stage pre-heater over 4 stage and 5 stage preheater is that even though there is slight increase in pressure drop and power consumption there is a considerable reduction in thermal energy as shown in Table 14.

Table 14 Performance of Different Pre-heater Systems

Parameters	4-STAGES	5-STAGES	6-STAGES
Pressure drop across preheater and calciner	100%	114%	127%
Fuel consumption	100%	97%	95%
Preheater id-fan specific power consumption	100%	104%	111%
Installed cost of the pyro processing system	100%	111%	122%

Rotary Kiln Firing

Burners are used for firing different types of fuels in the kiln. The different types of burners used range from simple single-tube burner modern multi-channel burners. The multi-channel burners offer better flame shape control because of separate primary air channels.

Dual-fuel Burners

Dual-fuel burners use pulverised coal or coke, oil, natural gas or any mixture of these fuels. The burner may be fitted with extra ducts for secondary fuels such as plastic chips, wood chips, sewage sludge, etc. Standard types are available for any fuel combination and a maximum capacity ranging from 20 to 250 MW, catering for even the largest of rotary cement kilns. The key benefits include low primary air combustion, central fuel injection and adjustable air nozzle area.

3.8 COOLERS

Coolers are used to transport clinker from the kiln to the clinker delivery system. The clinker cooler serves to cool clinker from 1400^0C at which it leaves the kiln to less than

100^0C by exchange of heat with ambient air which is thereby preheated before entering the kiln or pre-calciner as combustion air.

Types of Coolers

- Rotary cooler
- Planetary cooler
- Reciprocating grate cooler

Rotary Cooler

The rotary cooler consists of a revolving cylinder, following the rotary kiln. Rotary kilns of 60 - 90 m length are supplied with rotary coolers of 2 - 5 m diameter and 20 - 50 m length. The slope of rotary coolers is in the range from 4-7º to the horizontal; they are mostly arranged in opposition to the kiln's slope, since they are frequently located underneath the rotary kiln.

Rotary coolers are operated with revolutions in the range from 0 to 8 rpm. About to 70% of the drum's length is refractory lined. Rotary coolers are supplied with flights for lifting and dropping the clinker to get a thorough contact with the cooling air, and thus to increase the efficiency of the cooler.

The negative pressure in the rotary kiln induces suction of cold air through the open end of the rotary cooler; the cooling air passes the rotary cooler in cross-current to the motion of the clinker. The temperature of the cooling air entering the rotary kiln is about 400-750°C.

The clinker leaving the rotary kiln with a temperature of 1300 – 1350°C enters the rotary cooler. The temperature of the clinker leaving the rotary cooler is in the range of 150-300°C.

Planetary Cooler

The planetary coolers consist of several, mostly 10 or 11 sheet metal cylinders arranged along the circumference of the hot kiln end, forming an integral part of the rotary kiln. These coolers revolve together with the rotary kiln, with separate drive. The cooling tubes are refractory lined, up to about 25 % of their length; for better heat transfer, the remainder of the length is supplied with chains or flights. Cooling occurs cross-currently.

The total cooling air enters the kiln as combustion air. The motion of the clinker in the planetary coolers is mostly parallel to the motion of the clinker in the rotary kiln; however, there are also satellite coolers supplied with internal construction, capable of conveying the clinker in the opposite direction.

In this cooler tubes are mounted on the kiln shell and they rotate along with the kiln. The clinker leaving the kiln enters the cooler tubes wherein it is cooled before leaving the cooler.

Grate Cooler

The clinker grate cooler with air quenching effect, also known as the Fuller-cooler, is operated in conjunction with the rotary kiln.

Fuller grate cooler

The objective of Fuller cooler is to improve cement quality resulting from rapid cooling of the clinker as well as provide good heat exchange between the hot clinker and the cooling air.Compared to the rotary cooler, the Fuller cooler as such requires about 20 % less space. The Fuller cooler enables complete control of the secondary air and the clinker temperature. The heat losses of this cooler by radiation and convection are extremely low.

The Fuller cooler develops a fast initial cooling of the clinker; this fact is of great importance for the formation of tri-calcium silicate. This cooler allows for clinker input temperatures of about 1360 - 1400 ºC, which increases the thermal efficiency up to 72-75 %. The application of excess cooling air results in cooling of the clinker down to 65 °C this temperature allows an immediate grinding of the clinker to finished cement.

In contrast to the rotary and planetary coolers where cooling of clinker is predominantly performed by transverse air current the Fuller cooler, cools with a combination of cross-current and counter-current air.

The comparison between conventional grate coolers vs. modern grate coolers is presented in Table 15.

Table 15 Comparative Ranges of Process Design Parameters

	Conventional Grate Coolers	Modern Grate Coolers
Clinker loading (tpd / m^2)	35 – 50	50 - 65
Cooling air requirement (Nm3/kgcl)	2.2 – 2.6	1.5 - 1.9
Maximum air velocity(Nm3/m2/sec)	1.15 - 1.55	1.15 - 1.55

Source : Training Notes, NCCBM

Compared to conventional grate coolers, modern coolers have higher clinker loading with low cooling air requirement thereby saving in power consumption of cooler fans and cooler efficiency is higher.

Table 16: Heat Recuperation in Conventional and Modern Coolers

Cooler Type	Clinker Temp.^{0}C	Cooler Loss kcal/kgcl	Avg. Air Temp. ^{0}C
Low Efficiency Grate Cooler	675	155	840
Good conventional Grate Cooler	560	125	930
Cooler based on air beam technology	475	105	1000
Cooler based on improved air beam technology/ full static grate.	390	85	1065

Source : Training Notes, NCCBM

4. BEST PRACTICES

4.1 WASTE HEAT RECOVERY SYSTEM

The adoption of waste heat recovery systems in Indian cement manufacturing facilities has been relatively slower compared to its global peers. Out of over 190 large cement plants in the country, only about 20 cement plants have adopted WHR systems. Estimates indicate that the waste heat recovery potential in Indian cement industry is close to 500 MW while the installed capacity till date is only about 275 MW. This indicates the huge opportunity for adoption of waste heat recovery in Indian cement industry.

In case of dry process cement plants, nearly 40% of the total heat input is available as waste heat from the exit gases of the pre-heater 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 pre-heater 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 cooler or pre-heater and, in that case, waste heat recovery potential will be further reduced. Power production utilizing hot gases from the pre-heater and hot air from the cooler requires a heat recovery boiler and a turbine system.

Based on the chosen process and kiln technology, 8-10 kWh/t clinker can be produced from cooler exhaust air and 9-12 kWh/t clinker from the pre-heater gases if the moisture content in the raw material is low and if volume of hot gas/air for drying is less. So in total up to 22 kWh/t clinker or up to 25% of the power consumption of a cement plant can be produced by using WHR technologies without changes in kiln operation. Waste heat recovery technology will result in 0.8 – 1.3 kg CO_2 reduction in emissions.

4.2 USE OF ALTERNATE FUELS AND BIOMASS

Fossil fuels and raw materials used by Indian cement plants can be replaced to a large extent with AFR. The carbon intensity of the fuel will depend on the extent of usage of AFR in the total fuel used by the cement plant. It is widely accepted that cement kilns are particularly well suited to manage different kinds of wastes by using them as AFR, considering the high temperature and long residence time available in the cement kiln.

Life-cycle assessment (LCA) shows that co-processing of waste as AFR in the cement kiln has a much lower environmental impact than disposal through incineration or landfill.

The global average alternative fuel use in the cement industry is currently 4.3% of total thermal energy consumption. In some countries, the average use is as high as 30%, whereas in India the average is 0.6% (IEA and WBCSD, 2013). Typical wastes streams that can be used as AFR in the Indian cement industry include the following:

- industrial wastes;
- pre-processed industrial wastes;
- sorted municipal solid waste (MSW);
- refuse-derived fuel (RDF) from MSW;
- discarded tires and tire chips;
- expired consumer goods e.g. medicines and fast moving consumer goods (FMCG);
- waste oils and solvents;
- non-recyclable plastics, tex 27-30 tiles and paper residues;
- biomass (such as rice husk, coconut shells and groundnut shells);
- effluent treatment sludges from water and
- wastewater treatments plants; and
- Lime sludges from paper and allied industries.

Given the wide range of waste that can be used as AFR, and their different moisture and heat content and given the different fuels that can be displaced by the use of alternatives, it is challenging to quantify the impact of AFR on total electrical and thermal energy consumption. However, their use may have an important impact in reducing the carbon footprint of the cement industry.

Currently thermal energy consumption accounts for 31 % of the GHG emissions. Even if efforts are taken to replace the conventional fossil fuel with any of the wastes or alternate fuel by at least 10 %, this will result in reducing the emissions by about 22 kg CO_2 /MT cement (CII, 2010).

4.3 CLINKER SUBSTITUTION

Replacing the clinker with additive materials such as fly ash / blast furnace slag not only reduces the power consumption, but also protects the environment, conserve the limestone and coal as well as reduce the amount of GHG emissions. It is estimated that for every 1% of increase in blended cement production, CO_2 emission will be reduced by approximately 2.2 – 6.0 kg per MT of cement keeping all other parameters constant (CII, 2010).

Bureau of Indian Standards (BIS), as per the latest types of specifications of blended cements allows addition of maximum 35 % of fly ash in PPC (Portland Pozzolana Cement) and blast furnace slag to a maximum of 65% in PSC (Portland Slag Cement) subject to meeting other quality requirements such as setting time, compressive strength etc., Currently the fly ash addition in PPC varies between 15% and 32% with an average of 28% as against the maximum allowed norm of 35%. It is estimated that for every 1% of increase in additives in blended cement production, CO_2 emission will be reduced by approximately 4.0 – 6.5 kg per MT of cement keeping all other parameters constant (CII, 2010). Several different clinker substitutes can potentially be used in cement, and their relative merits and availability are presented in Table 17.

Table 17 Characteristics of Clinker Substitutes in India

Clinker substitute	Source	Characteristics of the blended product compared to OPC	
		Positive	**Limiting**
Fly ash	Coal fired Power plants	Higher long-term strength, increased durability, lower water consumption, better workability.	Relatively lower early strength, logistic barriers (distance between other industries and cement plant)
Ground blast furnace slag (GBFS)	Iron and steel Industry	Improved chemical resistance, higher long-term strength	Relatively lower early strength, logistic barriers (distance between other industries and cement plant)
Other Blending materials	Non- ferrous industries, mineral processing industries	Increased durability	Relatively lower early strength, presence of minor constituents(e.g. magnesium oxide[MgO]), logistic barriers (distance between other industries and cement plant)
Limestone	Limestone deposits	Increased workability, higher long term strength	none

Source :(IEA and WBCSD, 2013)

4.4 IMPROVEMENTS IN ELECTRICAL & THERMAL ENERGY CONSUMPTION

Adopting the latest technologies, actively participating in the energy conservation activities and implementing the projects will result in further reduction of specific power and thermal energy consumption of Indian cement industry.

It is estimated that for every 1 kW/MT of cement reduction in specific power consumption, CO_2 emission will be reduced by approximately 0.9 – 1.6 kg CO_2 per MT of cement and for every 10 kcal / kg clinker reduction in specific heat consumption, CO_2 emission will be reduced by approximately 2.6 – 3.6 kg per MT cement (CII, 2010).

4.5 PRODUCING COMPOSITE CEMENT

One of the latest trend & recent development in the cement industry is to produce composite cement where in clinker is replaced with both blast furnace slag and pozzolonic material like fly ash.

Composite cement will have the best properties of cement like low heat of hydration, resistance against chemical attack with the equivalent strength portion. Producing composite cement ensures reduction in specific energy consumption, complete utilization of waste and conservation of limestone and hence greenhouse gas emission reduction.

Composite cement can have the highest cement to clinker ratio as high as 3.33 as the cement can be made from 30 % clinker (CII, 2010). Currently there is no quality standard for producing such type of cement in India.

EN 197 - 1: 2000 cement type V has two composite cements with the following cement composition (Table 18) comprising higher percentages of blast furnace slag and Pozzolana or fly ash.

Table 18 Composition of Composite Cements

Composition of Composite Cements under EN 197 – 1 : 2000					
Cement	**Cement Notation**	**Clinker content %**	**Blast Furnace Slag %**	**Pozzolana/ Fly Ash %**	**Gypsum %**
Composite cement	CEM VA	40-64	18-30	18-30	0-5
Composite cement	CEM VA	20-39	31-50	31-50	0-5

Source :(CII, 2010)

4.6 LIMESTONE BASED CEMENT/LOW CARBON CEMENT

Bureau of Indian Standards (BIS) which controls the standards for various types of cements produced in the country, has allowed up to 5 % of limestone/slag/ similar material addition in cement.

Presently many cement plants are not adding the filler due to more focus on higher one day strength requirements to maintain competition. The one day strength does not improve quality of construction as a whole and results in higher specific power consumption and reduces the additives.

Considering the fact that normal household constructions do not require high grade cement, using limestone (up to 20%) in cement can reduce energy consumption and GHG emissions. It is estimated that increasing the addition of limestone in OPC as filler from the existing level by 10% will result in GHG reduction of 25.0 kg CO_2 /MT cement (CII, 2010).

A number of low carbon or carbon-negative cements are currently being developed by some companies that expect to build pilot plants in the near future. The physical properties of these cements appear to be similar to those of OPC, and hold equally strong potential for the global and Indian cement industries. These new processes are still at the development stage, but are advancing steadily (IEA and WBCSD, 2013).

- **AETHER CLINKER PROJECT** aims to develop a new class of lower-carbon clinkers to be used in cement production. The clinker can be made in existing cement plants (after certain process adaptations have been made) with the same raw materials but, crucially, needs less energy. Aether cements are expected to offer similar performances to conventional OPC in various concrete applications, but trials are still underway. During the first industrial trial in February 2011, 5000 tonnes of Aether clinker was produced, confirming the feasibility of industrial-scale production and the expected 25% to 30% fewer CO_2 emissions per tonne of cement than OPC.

- **CALERA'S KEY PROCESS** is the technology associated with carbon capture and conversion to stable solid minerals. This involves bringing gas from the power plant in contact with alkaline water to form soluble carbonates, which then react with hard water to form solid mineral carbonates and bicarbonates. These solid mineral carbonates and bicarbonates now contain CO_2 that would have been emitted into the air. After removal from the water and with further processing, the solids have value in a number of construction applications. However, alone, it does not produce cement or concretes with properties that meet the requirements of cement standards, and is therefore not currently envisaged as a process that would produce a cement-like product for widespread construction use.

- **CALIX CEMENT** is produced in a reactor by rapid calcinations of dolomitic rock in superheated steam. The particles of rock are dropped into a vertical tube of superheated steam, which causes the particles to explode into grains, increasing the overall surface area. Those grains then react with the steam, oxidizing the surfaces, and the residue can be ground into a powder and mixed with sand to form a powder. The CO_2 emissions from this process can be captured using a separate CO_2 scrubbing system.

- **CELITEMENT** is made through a novel production process, the main stage of which requires temperatures of about 200°C,compared to 1 450°C for conventional cement manufacture. Its developers claim that the process emits 50% less CO_2 than OPC manufacturing. The new cement is characterized by a low consumption of resources: approximately one-third of the amount of limestone is required and it can be done completely without a gypsum additive. Celitement GmbH has engineered a pilot plant now in operation to supply sufficient quantities for testing of basic properties and recipes.

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

In the long term, low-carbon cements may offer opportunities to reduce the CO_2 intensity of cement production.

4.7 EMERGING TECHNOLOGIES

Emerging technologies that could significantly improve CO_2 emissions reduction of the Indian cement industry are at various stages of development: use of mineralisers, fluidized bed advanced cement kiln system (FAKS), carbon capture and carbon use for algal growth for biofuels production, geo-polymer cement and use of nanotechnology in cement production (IEA and WBCSD, 2013).

- **Use of Mineralisers to Improve Combustion of the Raw Mix**

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

- **Fluidized-bed Advanced Cement Kiln System (FAKS)**

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

- **Algal Growth Promotion and Use of Biofuels**

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

- **Geo-Polymer Cement**

Geo-polymer 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 alumino silicate polymer network forms, which is responsible for the relatively high strength of the hardened product. Geo-polymer cements are already in use but not widely.

- **Use of Nanotechnology in Cement Production**

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

Activation of raw materials and cements, which may provide enhanced reactivity during Clinkerization (for raw materials) and hydration (for cement).

The most studied and well-reported area is the use of Nano-particles, such as Nano-silica, in cement mortar and concrete. Potential health hazards associated with the handling and use of Nano-particles need to be studied, understood and mitigated.

- **Carbon Capture and Storage**

Among the newer technologies for CO_2 emissions reduction presented in this roadmap, only CCS is considered to become commercially available over the timeframe analyzed. CO_2 capture through post- and oxy-combustion in the cement industry is currently at the pilot stage. If pilot testing is successful, and actions are quickly taken to overcome the barriers to CCS, it could contribute between 86 $MtCO_2$ and 171 $MtCO_2$ of the emissions reduction from the Indian cement industry by 2050. Carbonate looping – an adsorption process in which calcium oxide is put into contact with the combustion gas containing carbon dioxide to produce calcium carbonate – is at conceptual design stage.

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

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

Oxy-combustion technologies have their own disadvantages, however. While they can avoid the high energy costs associated with all post combustion capture techniques, the cost of oxygen gas production is high. Moreover, significant re-engineering of the plant may be needed to accommodate altered thermodynamics and material stress of operation in an oxygen-rich environment.

- **Transport Logistics**

Reducing transport emissions by locating the grinding plant nearer to the fly ash / slag source, bulk packing instead of retail packing, bulk transport through bulk tankers and rail instead of smaller size lorries and back haulage for cement dispatch and raw material receipt are some other smaller initiatives that can be adopted to reduce the GHG emissions by 0.5 kg CO_2 /MT cement.

It can be noted that Road transport releases 2.5 times the GHG emission than rail per MT of material transported for the same distance because of the bulk transport, better (CII, 2010).

5. CASE STUDIES

As part of the study, field studies are conducted at 3 cement plants for preparing detailed case studies of GHG reduction projects in 3 cement plants. The plants for case studies were selected based on their initiatives and performance in terms of implementing several projects that have resulted significant energy savings and GHG emission reductions.

The plants have implemented many GHG reduction projects over the period and the key projects in terms of GHG reduction, technological innovation are selected and presented in the following sections.

5.1 INSTALLATION OF NEW HIGH EFFICIENCY SF COOLER IN LINE-1

Background

The Ramco Cements, Alathiyur had the conventional cooler in Line-1 designed for the capacity of 2200 TPD. The Preheater section was continuously upgraded to 3200 TPD with the same cooler. The cooler efficiency has reduced due to high loading on cooler.

Description of the project

The plant has replaced 3200 TPD conventional grate cooler with FLS cross bar cooler of capacity 3550 TPD. The table shows the operational parameters before and after the cooler upgradation. Productivity increased by 350 TPD of clinker, cooler loss was reduced by 60 kcal/kg clinker, power consumption in cooler section is reduced by 1.35 kWh/T clinker.

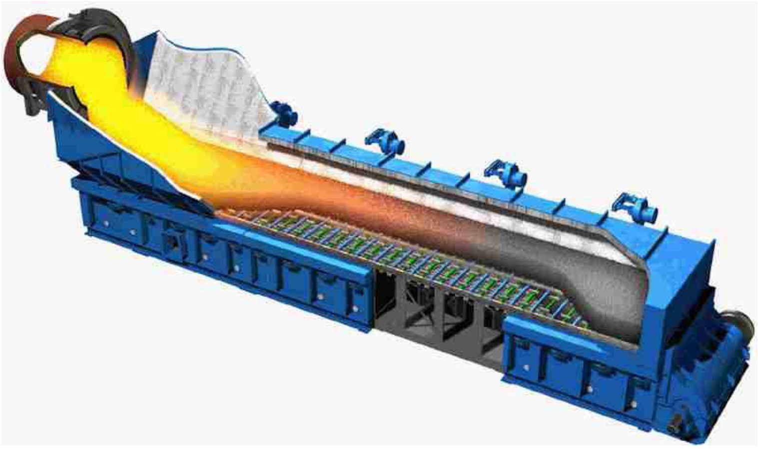


Figure 10 New High Efficiency SF Cooler in Line-1

Results Achieved

The details of results achieved presented in the following Table: 19

Table 19 Results achieved by installation of new high efficiency sf cooler in line-1

Parameter	Units	Before installation	After installation
Specific Energy Consumption	kWh/T clr	7.65	6.30
Thermal Energy Consumption	kcal/kg clr	200	140
Power Savings	MWh/year	1150	
Reduction in Cooler Loss	kcal/kg clr	60	
Coal savings	MT/year	8520	
Reduction in GHG emissions (Thermal + Electrical)	**T CO_2/year**	**22123**	

5.2 INSTALLATION OF RAW MILL-1 CLASSIFER WITH ENERGY EFFICIENT CLASSIFIER WITH VORTEX RECTIFIER

Background

The plant had installed Loesche mills for raw material. The raw mill was designed for feed moisture of 5% - 10%. Over a period of time the normal feed moisture increased to more than 10% causing the reduced raw mill output to 205-210 tph from 215-220 tph. During monsoon mill output was further reduced to 190 tph. Hot gas generator (HGG) has to be operated to meet clinker production. Since more heat was required for drying the raw material, the gas volume was to be increased in mill and thereby causing higher product residue. Kiln feed had to be reduced as the Raw mill was unable to support the raw meal requirement. At high residue of raw meal on 212 µm and high quartz %, problems related to clinker burning resulted in high free lime of more than 2.5%.

Description of the project

The plant has replaced the classifier LSKS 52 with LSKS 57 with inbuilt Vortex Rectifier (*first time in India*). Modified louvre and armour ring to maintain uniform gas flow profile inside the mill.

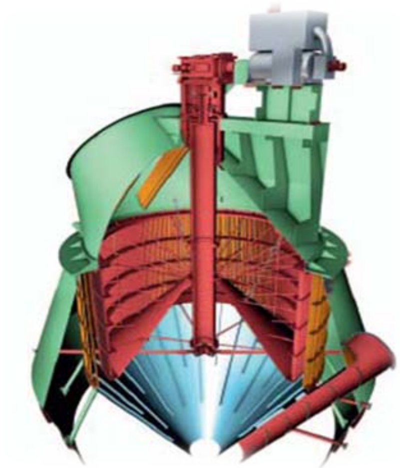


Figure 12 Old Classifier without vortex rectifier

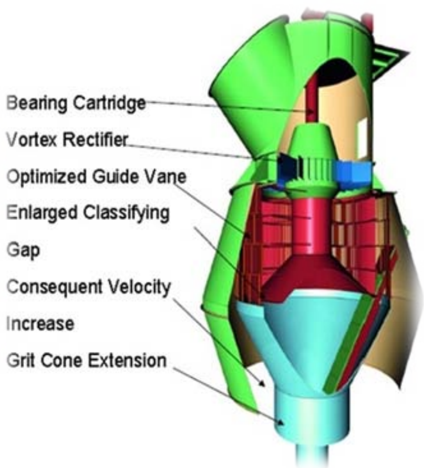


Figure 11 New Classifier with vortex rectifier

Results Achieved

The details of results achieved presented as follows:

Table 20 Results achieved by installation of raw mill-1 classifer with energy efficient classifier with vortex rectifier

Description	Units	Before modification	After modification
Mill output (dry)	TPH	207	231
Residue @212µm	%	2-2.5	1.5-2
Specific Power Consumption			
Mill	kW/T	5.56	4.55
Fan	kW/T	6.33	6.28
Total Specific Power	kWh/T	11.88	10.82
Power Savings	MWh/year	2001	
Reduction in GHG emissions	**T CO_2/year**	**2591**	

5.3 INSTALLATION OF STEAM TRACER FOR DG AUX INSTEAD OF ELECTRICAL HEATING

Background

The plant has installed with 3 nos. of Diesel Generators (2 x 6 MW and 1 x 4 MW). The DG sets became standby after installation of 2 x 18 MW Coal Based Thermal Power Plant in 2005. During idle time, lube oil and jacket water temperature is to be maintained at 60°C to keep DG in warm up condition. To maintain the lube oil and jacket water temperature at 60°C, the electrical heaters were used.

Description of the project

Since the plant has Coal based Power Plant and plant get low pressure steam from the de-aerator. They have started using this steam to maintain lube oil and jacket water temperatures at 60°C instead of using Electrical Heaters.

Figure 13 Steam Heating System

Figure 14 Electrical Heating System

Results Achieve:

The details of results achieved presented in the following Table 21

Table 21 Results achieved by installation of steam tracer for dg aux instead of electrical heating

Description	Units	Before (with Electrical Heating)	After (with Steam Heating)
Average power consumption	kWh/day	2400	390
Savings in power	kWh/day	2010	
Annual savings	MWh/year	724	
Reduction in GHG emissions	**T CO_2/year**	**937**	

5.4 INSTALLATION OF VFD FOR LINE-2 CEMENT MILL BAG FILER FAN AND PRE-HEATER ID FAN

Background

Cement Mill bag filter fan and Pre-heater ID Fan in Line-2 were running in GRR mode. The speed of these fans can be controlled by varying the resistance in the rotor circuit results in power loss of the motors. The amount of power lost across the GRR depends on the speed at which the fan is operating which in turn depends on the operating step of GRR.

Description of the project

The plant has installed VFD for Line-2 Cement Mill bag filter fan and Pre-heater ID Fan to control the speed and avoid the power loss in the GRR to have optimum control on speed. This has resulted in a significant power savings in the fans power consumption.

Figure 15 VFD for Line-2 Cement Mill bag filter fan

Figure 16 VFD Line-2 Pre-heater ID Fan

Results Achieved

The details of results achieved presented in the following Tables 21 and 22

1. Line-2 Cement Mill bag filter fan

Table 22 Results achieved by installation of VFD for line-2 cement mill bag filer fan

Description	Units	Before (with GRR)	After (with VFD)
Average power consumption	kW/hr	2000	1750
Savings in power	kW/hr	250	
Annual savings	MWh/year	2040	
Reduction in GHG emissions	**T CO_2/year**	**2642**	

2. Line-2 Pre-heater ID Fan

Table 23 Results achieved by installation of VFD for PreHeater ID Fan

Description	Units	Before (with GRR)	After (with VFD)
Average power consumption	kW/hr	2000	1800
Savings in power	kW/hr	200	
Annual savings	MWh/year	1656	
Reduction in GHG emissions	**T CO_2/year**	**2145**	

5.5 OPTIMISATION OF PRESSURE DROP IN DUCTS USING CFD IN CEMENT MILL-1 & 2

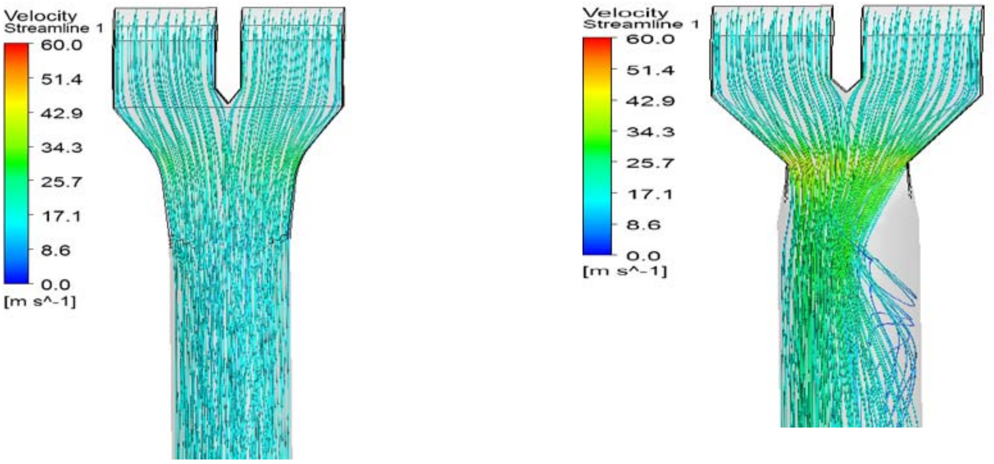
Background

Due to uneven duct area in the Line-1 Cement Mill bag house outlet duct and Line-2 Cement Mill fan outlet duct, there was a high pressure drop in both the ducts due to turbulent flow. This led to high electrical power consumption in Line-1 Cement Mill bag house fan and Line-2 Cement Mill fan.

Description of the project

The plant conducted a CFD analysis of air flow in both the ducts and modified the ducts and reduced the pressure drop. This modification resulted in power savings in Line-1 Cement Mill bag house fan and Line-2 Cement Mill fan.

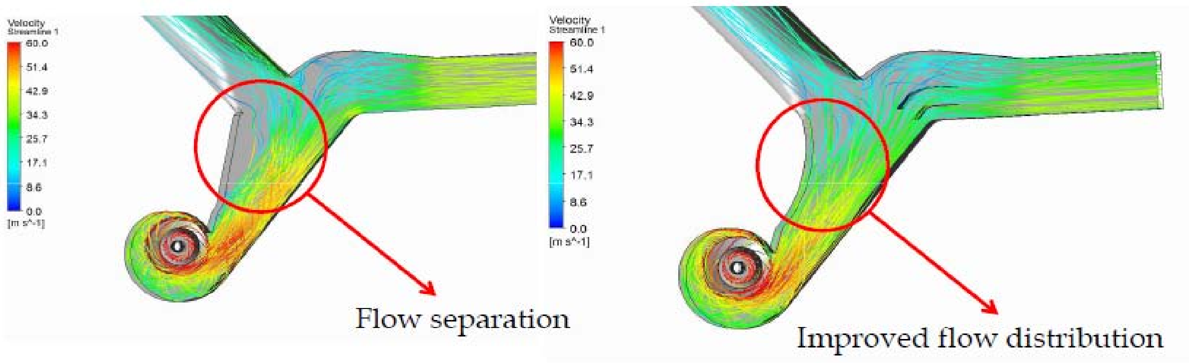
Figure 17 Line-1 Cement Mill bag house fan



Before Modification **After Modification**

Figure 18 Line-2 Cement Mill bag house fan outlet duct:

Before Modification **After Modification**



Results Achieved

The details of results achieved presented below table 24

Table 24 Results achieved by optimisation of pressure drop in ducts using cfd in cement mill-1 & 2

Description	Units	Line-1 Cement Mill bag house fan	Line-2 Cement Mill fan
Power Savings	kW/hr	50	27
Annual Energy savings	MWh/year	554	
Reduction in GHG emissions	**T CO_2/year**	**718**	

5.6 MODIFICATION OF LINE-2 RAW MILL FAN INLET DUCT

Background

There was a high pressure drop across the Line-2 Raw Mill Fan inlet duct due to small suction area.

Description of the project

The plant has modified fan inlet suction box by increasing its area to reduce pressure drop across fan inlet suction box. This has resulted in Raw Mill Fan power saving of 85 kW.

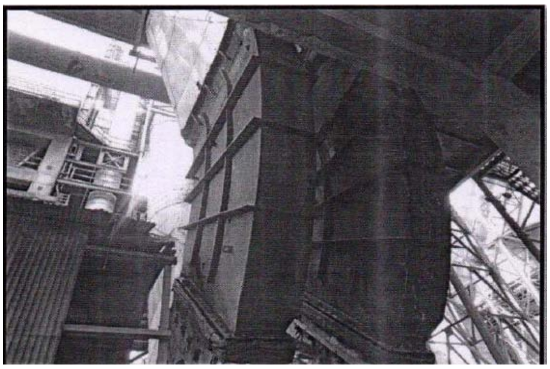


Figure 19 Raw Mill Fan Inlet Duct

Results Achieved

The details of results achieved presented below

Table 25: Results achieved by modification of line-2 raw mill fan inlet duct

Description	Units	Before Modification	After Modification
Average power consumption	kW/hr	1675	1590
Savings in power	kW/hr	85	
Annual savings	MWh/year	612	
Reduction in GHG emissions	T CO_2/year	793	

5.7 INSTALLATION OF ROTARY AIRLOCK IN LINE-2 COAL MILL

Background

There was false air ingression in to the Line-2 Coal Mill inlet which led to the higher power consumption of coal mill Booster fan.

Description of the project

The plant has installed Rotary Airlock in Line-2 Coal Mill inlet to reduce the false air ingression in to the mill. This measure has resulted the power saving of 20 kW in booster fan consumption.

Results Achieved

The details of results achieved presented below.

Table 26 Results achieved by installation of rotary airlock in line-2 coal mill

Description	Units	Value
Power Savings	kW/hr	20
Annual Energy savings	MWh/year	144
Reduction in GHG emissions	T CO_2/year	186

5.8 REMOVAL OF SILENCER FOR COOLER FANS AND ARRESTING LEAKAGES OF COOLER

Background

Cooler fans in Line-3 & 4 are having silencers, led to higher pressure drop and hence cooler recuperation efficiency was low and higher power consumption in the cooler section.

Description of the Project

Complete study was conducted and removed all the silencers of all cooler fans and modified the inlet section of the fans. By this measure the pressure drop and the Power consumption of fans has reduced

Complete study was conducted and removed all the silencers of all cooler fans and modified the inlet section of the fans. By this measure the pressure drop and the Power consumption of fans has reduced.

Before

After

Results Achieved

The details of results achieved presented in the following Table 27

Table 27 Results achieved by removal of silencer for cooler fans and arresting leakages of cooler

Description	Units	Value
Power Savings (after modification)	kWh/T clr	2.6
Annual Energy savings	MWh/year	5936
Reduction in GHG emissions	**T CO_2/year**	**7687**

5.9 OPTIMIZATION OF COAL HANDLING PLANT BY MODIFYING THE BELT FEEDER DRIVE ARRANGEMENT

Background

The plant was getting the coal from the coal handling plant of quantity 100 TPH only (1200 TPD). The power consumption of line-2 group was 338 kW/hr and the group runs for 12 hours.

Description of the project

The plant optimized the operation of coal handling plant by modifying the belt feeder drive arrangement. With this measure, now the CHP is operating for 7 hours for the same capacity with the reduced power consumption.

Results Achieved

The details of results achieved presented in the following Table: 28

Table 28 Results achieved by Optimization of Coal Handling Plant by Modifying the Belt Feeder Drive Arrangement

Description	Units	Before optimisation	After optimisation
Operational Hours	Hr	12	7
Average power consumption	kW/hr	338	366
Annual savings	MWh/year	359	
Reduction in GHG emissions	T CO_2/year	464	

5.10 UTILISATION OF ALTERNATE FUELS

Background

Vasavadatta Cement is unit of Kesoram Industries Ltd., situated at Sedam, Karnataka. Plant has 4 kilns of capacities 2400TPD, 3600 TPD, 4500 TPD & 4500 TPD.

Description of the project

For increasing the thermal substitution rate to feed different types of alternative fuels Vasavadatta Cement has installed HOTDISC in Kiln-3. The HOTDISC is a safe simple and effective combustion device that maximizes the substitution of fossil fuels by alternative fuels in a controlled manner. The HOTDISC is installed at pyro-processing unit-3 in Sep-2012.

This state of art technology is first of its kind in India, for cement industry to utilize refused delivered waste & tyres in cement rotary kiln as alternative fuel in efficient way with compliance with all environmental regulations. The HOTDISC is supplied by FLSmidth.

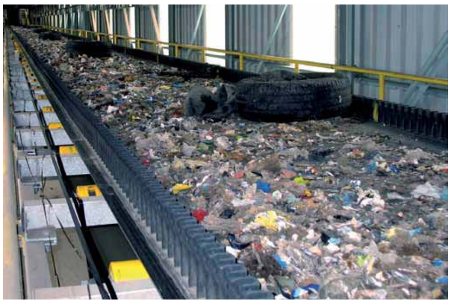
The plant is utilizing municipal waste, industrial waste, used tyres of vehicles, etc.

The HOTDISC is a simple combustion device, integrated with pre-heater and pre-calciner systems. The HOTDISC gives the flexibility to burn a wide variety of solid waste in sizes up to 1.2 m – from sludge or grains to whole truck tyres.

Features of HOTDISC Technology

- Combustion of alternative fuels takes place in Oxygen rich atmosphere.
- Variable retention time based on the type of alternative fuel is possible to ensure complete combustion.

Working principle:



As an integrated part of the kiln system, the HOTDISC is added onto the calciner and functions as a moving furnace. When alternative fuel, preheated raw meal and tertiary air are fed into the HOTDISC, it produces combustion gases, partly calcined meal and combustion residues. These are then processed in the calciner along with the other streams that go into the calciner. The result is calcined meal ready for the kiln and well-controlled emissions.

Benefits of HOTDISC:

- Reduction in Calciner coal firing TPH(TSR>30% based on AF availability)
- Reduction in laterite consumption due to steel wires in tires.
- NOx reduction (PPM) at main stack from based line test: 35%

***AFR feeding rate & other parameters with HOTDISC at Vasavadatta Cement*:**

- Feed rate of shredded tires : 3.5 TPD
- Feed rate of RDF : 10 TPH
- Speed of HOTDISC : 4-5 RPH
- Pre-heater meal diversion towards HOTDISC : 20%

Results Achieved

Table 29 Results achieved by Utilization of alternative fuels

Description	Unit	2014-15
Alternate Fuel usage	T/year	23265
GCV of alternate fuel	kcal/kg	5500
Thermal Substitution by Alternate fuel	Million kcal	127958
Weighted average of coal GCV	kcal/kg	5020
Coal Savings	T/year	25490
Reduction GHG emissions	T CO_2/year	51647

5.11 LOGIC MODIFICATION FOR IDLE RUNNING OF COAL HANDLING PLANT BELTS

Background

The plant is having coal reclaiming system with series of belt conveyors. Previously when a belt tripped / stopped due to any reason, the CHP belts in the downstream would run continuously. This idle running of belts was approximately 30 min in a day.

Description of the Project

The plant has modified the logic for Line-1 & 2 reclaimer group to avoid the idle running of the CHP belts. As per the modified logic command, the last belt of group should be started within 5 minutes after ON command is given to the group. If not, the entire group will be tripped through interlock protection. Such a way idle running of belts has been avoided.

Results Achieved

The details of results achieved presented below:

Table 30 Results achieved by Optimization of Coal Handling Plant by Modifying the Belt Feeder Drive Arrangement

Description	Units	Before modification	After modification
Average power consumption for Line-1 & 2 @ 30 min idle running	kWh/day	75.7	0
Annual savings	MWh/year	28	
Reduction in GHG emissions	T CO_2/year	36	

5.12 CONVERSION OF DELTA CONNECTED UNDER LOADED LT MOTORS TO PERMANENTLY STAR MODE

Background

The plant has 70 no's LT motors which are running constantly at low load.

Description of the project

Converted the delta connected and low load running motors to permanently star mode to avoid the power loss.

Results Achieved

The details of results achieved presented below

Table 31 Results achieved by conversion of delta connected under loaded motors to permanently star mode

Description	Units	Before (with delta connection)	After (with star connection)
Annual Energy Consumption	kWh/year	1495000	1065000
Annual Energy Savings	MWh/year	430	
Reduction in GHG emissions	**T CO_2/year**	**557**	

5.13 OPTIMIZATION OF COMPRESSED AIR USAGE AT PACKING PLANT

Background

In packing plant-2, the compressor installed is of capacity 75 kW (ML-75) and designed for 4 packers. During packer maintenance time (no loading time) or single packer running, the plant operating the same compressor.

Description of the project

The plant has modified the airline and provided one airline from small compressor (UP5-30) which is available in packing plant-2. This modification avoided the running of 75 kW compressor during the maintenance time (no loading time).

Results Achieved

The details of results achieved presented as follows:

Table 32 Results achieved by optimization of compressed air usage at packing plant

Description	Units	Before modification	After modification
Average power consumption	kW	40	22
Annual power savings	MWh/year	30	
Reduction in GHG emissions	**T CO_2/year**	**39**	

5.14 INSTALLATION OF WASTE HEAT RECOVERY SYSTEM FOR POWER GENERATION

Background

The India Cements Ltd, Vishnupuram Unit has two rotary kilns. The first kiln (Kiln-1) of 3000 TPD is equipped with two raw Mills of 100 TPH (Ball Mills with closed circuit, central discharge) and two coal Mills of 12 TPH (Ball Mills with closed circuit).The second kiln (Kiln-2) of 4600 TPD is equipped with Vertical Raw Mill of 300 TPH & Vertical Coal Mill of 45 TPH.

Description of the project

Waste Heat Recovery System of capacity 7.7 MW was installed in line-2. The operating load is around 8.6 MW. The hot waste gases coming out from the preheater and clinker cooler are used to produce steam and generate power. This has avoided power requirement from grid/ captive power plant.

Results Achieved

The details of results achieved presented in the following Table 33

Table 33 Results achieved by installation of waste heat recovery for power generation

Parameter	Unit	Kiln-2	
		PH Boiler	AQC Boiler
Year of Installation	Year	2004	2004
Rated Capacity of Steam Generation	TPH	28.2	14.63
Operating Capacity	TPH	29	14
Net Generation	Units/day	188360	
Kiln Capacity	TPD	4600	
Boiler Inlet temp (design)	0C	360	340
Boiler Inlet temp (operating)	0C	358	329
Boiler outlet temp (design)	0C	210	100
Feed Water Temperature	0C	200	200
Turbine Output (designed)	MW	7.7	
Turbine Output (operating)	MW	8.6	
Average annual generation on design capacity	MWh	60984	
Southern grid emission factor	t CO_2/MWh	0.81	
Reduction in GHG emissions	**t CO_2/year**	**49397**	

Generation Capacity- 7.7 MW

5.15 INSTALLATION OF IKN'S PENDULUM COOLER FOR UPGRADATION

Background

Jaypee Rewa Plant (JRP) Unit II started as a 4500 TPD SLC kiln with a twin string five stage pre-heater, precalciner and a Folax grate cooler. The capacity was gradually enhanced 5400 TPD with several in house improvements, including modification of pre-heater fans, replacement of cooler fans, increase in pre-calciner volume.

The earlier cooler was conventional cooler and demanding too many maintenance interventions and suffered frequent breakdowns so the company decided on a complete upgrade of the cooler.

Description of the Project

Jaypee selected IKN's pendulum cooler for up-gradation. An upgrade with IKN pendulum cooler resulted In Improved productivity, enhanced run time and lowered thermal and electrical energy consumption.

Results Achieved

The following Table shows the operational parameters before and after the IKN upgrade. A significant improvement was achieved in the run days after the upgrade. Specific heat consumption was Reduced by 15-20 kcal/kg of clinker, productivity increased by approximately 200 TPD. The Power in cooler section was also lowered by approximately 0.59 kWh/MT. The upgrade has resulted in improved productivity and run time and reduced thermal and electrical energy consumption.

Table 34 Results achieved by installation of IKN's pendulum cooler for upgradation

Parameters	Before	After
Production rate(TPD)	5550	5750
Tertiary air Temp(°C)	760	930
Specific Heat Consumption(kcal/kg clk)	710	690
Power in cooler section (kWh/MT clk)	4.47	3.88
Cooler vent air temp (°C)	220	200
Clinker temp (°C)	152	132

6. INTERNET OF THINGS (IOT)

As the world's expendable energy resources deplete and the industrial sector is being asked to deliver more to a growing population, energy efficiency has taken center stage to ensure the longevity of these energy resources, and the Internet of Things can play a crucial role. The emergence of the Internet of Things (IoT) almost certainly is the most important single development in the long evolution of energy management. The insight derived from data collected from new Internet-connected devices can be used to develop new services, enhance productivity and efficiency, improve real-time decision making, solve critical problems, and create new and innovative experiences.

Traditionally, many plants do not have the technology in place to track and measure energy use. On top of that, information on a plant's energy production and consumption is not consolidated into a single place. Energy production and consumption data is often not visible in real time and is not presented at a level granular enough to reflect how changes in behaviour affect energy use. With limited information at their disposal, energy managers can have a difficult time finding the places where energy use could improve. To develop a clear energy-saving strategy and drive energy-saving behaviour, managers need to boost monitoring capabilities and this data needs to be coordinated into a single system.

The Internet of Things (IoT) captures information seamlessly from the sensors and machines that monitor all aspects of the manufacturing process. The information it returns offer greater visibility into actionable data that can result in significant energy savings. Network sensors track energy performance, monitor for leaks and flag any subpar operating situations. Adding Internet of Things sensor technology to a plant allows for real-time alerts that notify energy managers about wasteful situations. Energy managers can then take timely action before their operation loses large amounts of money. Further, the Internet of Things gets the right information to the right expert– whether that person is an onsite manager, an off-site facility specialist, or a third party expert—when they need it, so they can make the best decisions to improve energy performance.

7. ABBREVIATIONS

GHG – Green House Gases

GDP – Gross Domestic Product

IPCC – Intergovernmental Panel on Climate Change

GWP – Global Warming Potential

Gt.CO_2 – Giga Tonne Carbon dioxide

MTOE – Metric Tonne Oil Equivalent

RPS – Renewable Portfolio Standards

TPD – Tonnes per Day

AOX – Absorbable Organic Demand

BOD –Biological Oxygen Demand

COD – Chemical Oxygen Demand

ADT – Air Dried Tonne

GCV – Gross Calorific Value

NCV – Net Calorific Value

TOE – Tonne Oil Equivalent

Mkcals- Million Kilo calories

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