NCPC

INDUSTRIAL EFFICIENCY IN SOUTH AFRICA

PART 2

IEE GUIDELINE FOR ENERGY EFFICIENCY WITHIN THE

CEMENT MANUFACTURING INDUSTRY IN SOUTH AFRICA

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Department:
Trade, Industry and Competition
REPUBLIC OF SOUTH AFRICA

CSIR
Touching lives through innovation

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LIST OF ACRONYMS

AFR	Alternative Fuel and Raw materials
BAT	Best Available Technologies
EnMS	Energy Management Systems
ESO	Energy Systems Optimisation
FLC	Fluidised Conveying
HEM	High-Efficiency Motor
HT	High Tension
IEE	Industrial Energy Efficiency Project
NCPC-SA	National Cleaner Production Centre South Africa
NOx	Nitrogen Oxide
SEU	Significant Energy User
TSR	Thermal Substitution Rate
UNIDO	United Nations Industrial Development Organization
VFD	Variable Frequency Drive
VSD	Variable Speed Drive

1. INTRODUCTION

The National Cleaner Production Centre-South Africa (NCPC-SA) is the country's leading resource-efficiency programme funded by the South African Government through the Department of Trade, Industry and Competition. In 2016, the NCPC-SA embarked on Phase II of its flagship Industrial Energy Efficiency Project (IEE Project), in collaboration with international stakeholders like The Global Environment Facility, The United Nations Industrial Development Organization (UNIDO) and the Government of Italy. One of the key components of the Phase II project is the strengthening of policy implementation and support frameworks for energy management systems (EnMS), energy systems optimisation (ESO) and the ISO 50001 Energy Management Standard in South Africa.

UNIDO has committed itself to promote the achievement of the sustainable development goals as espoused by the United Nations in its drive to reduce the effects of climate change. The main objective of the UNIDO IEE Programme in South Africa is to effect sustained energy management and efficiency practices in industry of developing countries and emerging economies to reduce the environmental pressure of economic growth while increasing productivity, helping to generate economic growth, creating jobs and alleviating poverty.

The SA IEE Phase II Project has worked with multiple government departments and agencies to assist in implementation and coordination of policy and regulatory mechanisms. The expected outcome of this project is enhanced promotion of investment in IEE through the provision of industrial support in the cement manufacturing sub-sector. This is envisaged to be achieved by providing technical assistance and capacity building to enhance existing and inform future regulatory frameworks that will support EnMS and ESO uptake and strengthen the coordination of associated activities across the industry in South Africa.

1.1 Why this guide

This guideline has been developed for the cement manufacturing sub-sector to provide guidance and stimulate improvement in energy performance within the sub-sector. It is aimed primarily at industry and is applicable to both fully vertically integrated and partially integrated manufacturers. It is also independent of plant capacity.

The intent of this guide may thus be described as:
- Provide guidance and awareness with regard to energy performance within the cement sub-sector.
- Promote and stimulate industry to improve its energy performance based on documented improvement opportunities.
- Assist companies to develop their own improvement opportunities.
- Provide a reference for all manufacturers by showcasing what has been achieved.

1.2 Development of the guide

The guide has been developed based on field experiences within South Africa. Thus, it is based on actual achievements and improvement opportunities. In some cases, the improvements have been specifically quantified based on the actual improvement opportunity, while in others the improvements have been inferred from overall reduction in energy consumption. In some cases the improvement has been indexed to maintain some form of client confidentiality.

The scope of this guide includes the manufacturing processes from the processing of the raw materials (limestone) at the plant to its distribution (bulk or packaged) to the end use. It excludes the mining processes and the transporting of the final product.

1.3 How to use this guide

The guide describes the manufacturing process and then considers opportunities in each segment of the manufacturing process. Where available, savings have been quantified based on a full-time operation (24 hours a day, seven days a week). The guide also describes best available technologies (BAT) where applicable and can be used by both large and small manufacturers.

It will allow the reader to:
- Identify processes that are common to the user,
- Focus on the processes that offer good opportunities,
- Identify and in some cases quantify improvement opportunities, and
- Gain confidence that the opportunities have already been implemented and savings have actually been achieved in similar manufacturing facilities.

The improvement opportunities have been divided into:
- Management,
- Process,
- Utilities, and
- Other energy.

A number of case studies from the South African cement industry have also been included. These provide a good reference for what has been achieved and should be used as a platform from which other cement manufacturing companies can develop their own improvement strategies.

2. OVERVIEW OF CEMENT INDUSTRY

"Cement and concrete have been used to build durable structures for quite some time. The Coliseum in Rome, completed in 80 AD, is a good example of how a concrete structure can withstand time. The cement used by the Romans was produced using locally available raw materials, chalk and volcanic ash heated in open fires. The modern version of cement, called Portland cement, was developed back in the early 19th century and has been improved ever since".[1]

Cement mixed with water, sand and gravel forms **concrete**, which is what the vast majority of cement is used for. Cement mixed with water, lime and sand forms **mortar**. The cement acts as a glue or hydraulic binder as it hardens and binds the aggregates (sand and gravel) when mixed with water.

There are 27 types of common cement that can be grouped into five general categories. They are classified according to the clinker content, as well as other additives that change the physical and chemical properties of the cement.

A value chain for cement is presented in Figure 1. Cement is most commonly used in South Africa in three forms. Bagged cement in the 50kg paper bag is probably the most commonly known end usage. Used in residential, commercial and industrial applications for smaller projects or larger projects with a slow completion rate. Ready mix is used in large construction projects where the end user would specify a type of cement. The supplier would blend and add the water providing an instant ability to caste the cement in large quantities on arrival at site. Pre-cast and concrete products are made by intermediaries purchasing cement and then manufacturing finished goods like lintels or other decorative type concrete products.

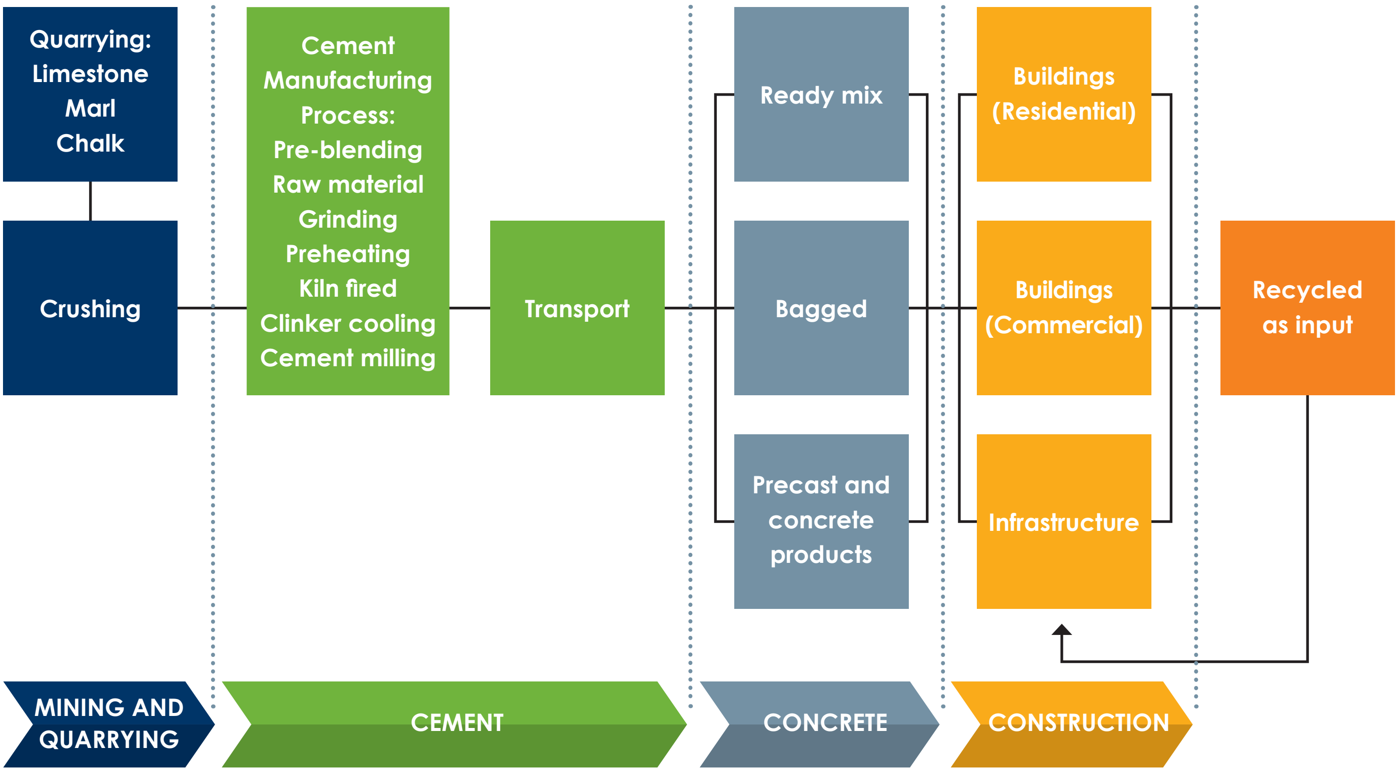


Figure 1: Cement Value Chain[2]

[1] Cembureau; Cement, concrete & the circular economy; page 4. Available from https://circulareconomy.europa.eu/platform/sites/default/files/cement_concrete_the_circular_economy.pdf. Accessed 27 April 2023.

[2] S Lowitt. Towards Decarbonisation of the South Africa Cement Industry: Opportunities and Challenges. Trade & Industrial Policy Strategies (TIPS). July 2020

2.1 International Cement Context

According to CEMBUREAU (2022), cement production worldwide is 4.17 billion tonnes. Of this, China produces 57.2%, India 7% and the USA 2.1%. Other significant cement-producing countries include Brazil, Turkey and Pakistan. South Africa is estimated to produce 15 million tonnes per annum, representing less than 0.3% of total world cement production.

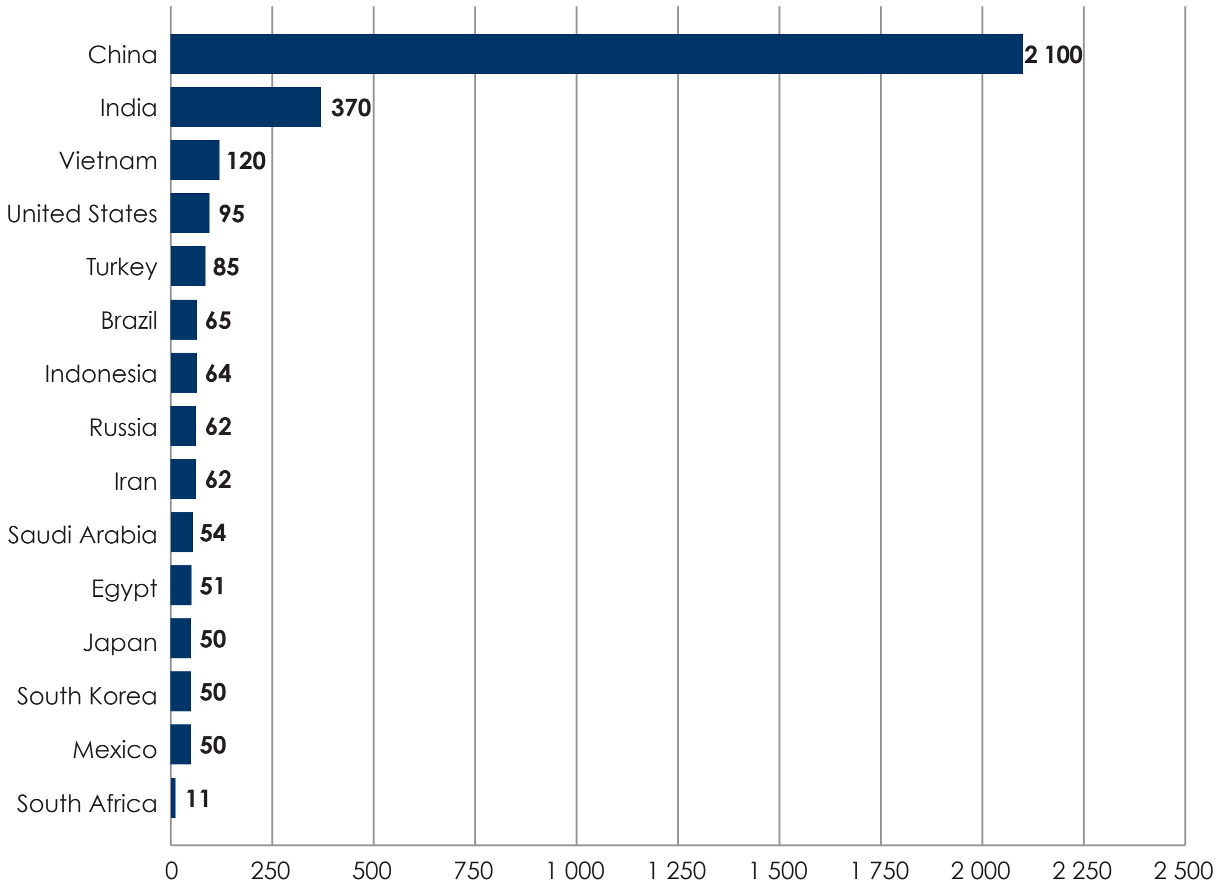


Figure 2: Worldwide Cement Production per Country (2020)[3]

Figure 3 shows the electricity use per ton of cement in selected countries and regions. Currently, India enjoys the use of the BAT to achieve an electrical energy intensity of 75 kWh/ton. The average intensity for G20 countries is 85 kWh/ton. This figure is, however, skewed by China which produces 57.2% of total world production. The average is closer to 91 kWh/ton, which is significantly lower than for Africa at 102 kWh/ton. The USA and Canada have some of the highest intensities.

[3] https://www.statista.com/statistics/1256776/production-capacity-of-cement-worldwide-by-country/ . Accessed Jun 2022.

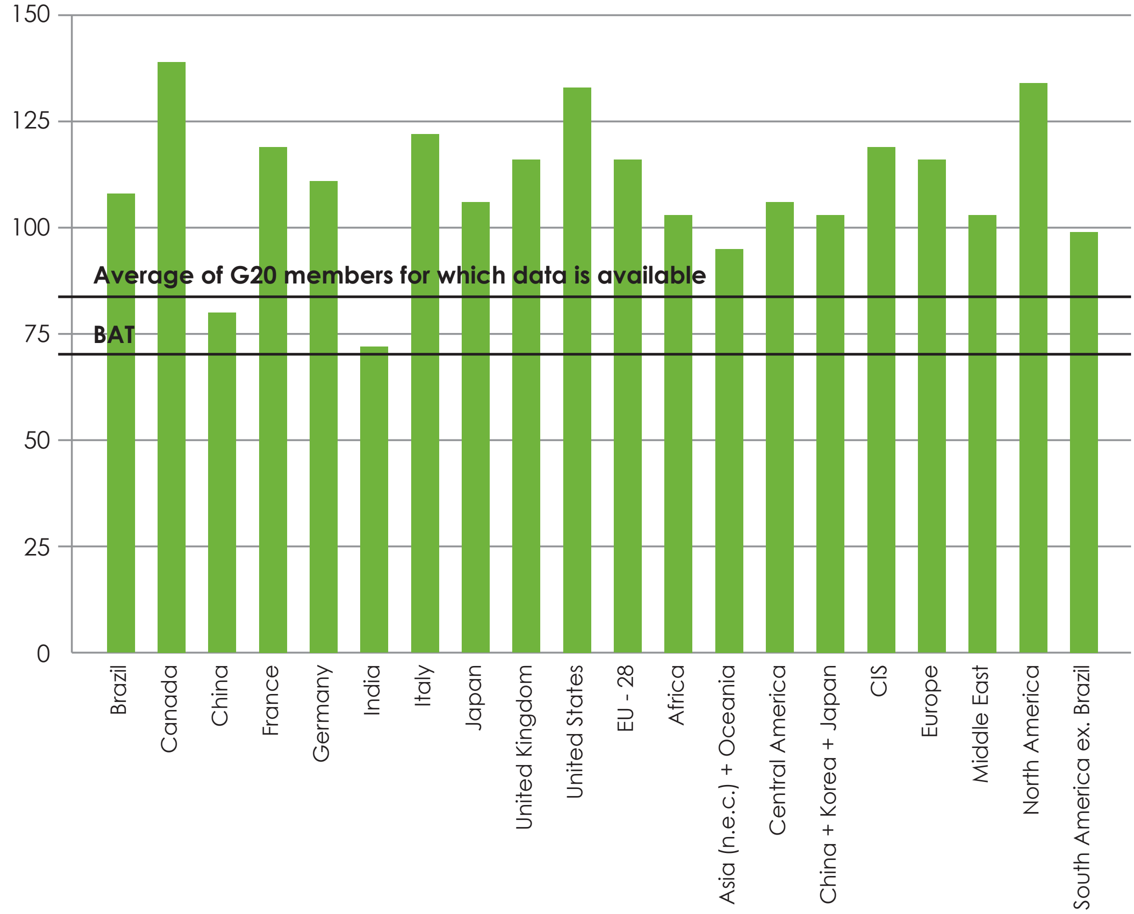


Figure 3: Electricity Usage in Cement Production[4]

2.2 South African Cement Context

South Africa has a population of just more than 60 million, equal to that of Tanzania. Its economic growth in the years 2018 and 2019 was only slightly above the zero mark. In 2020, the economy shrank by -7.0% and Moody's downgraded South Africa's sovereign credit rating to 'junk' status. Cement production has been in decline from close to 15Mt in 2018 to only 10.8 Mt in 2020[5].

In 2016, there were six cement producers in the South African market. According to work done by Lowitt (2020), the estimated market share at the time was PPC at 22%, NPC at 15%, Sephaku at 12%, AfriSam and Lafarge at 9% each and Mamba at 5%. A further 5% was imported and the rest were considered third-party blenders. The six cement producers with a combined cement capacity of 19.5 Mt/a led to a cement production capacity utilisation rate of 55.4% for 2020.

[4] https://www.iea.org/data-and-statistics/charts/electricity-use-per-tonne-of-cement-in-selected-countries-and-regions-2018. Accessed Jun 2022.

[5] Adapted from https://www.zkg.de/en/artikel/zkg_Latest_trends_in_Africa_s_cement_industry-3696965.html. Accessed Mar 2023.

2.3 The Cement Manufacturing Process

Cement manufacturing can be divided into three distinct phases and is shown in Figure 4.

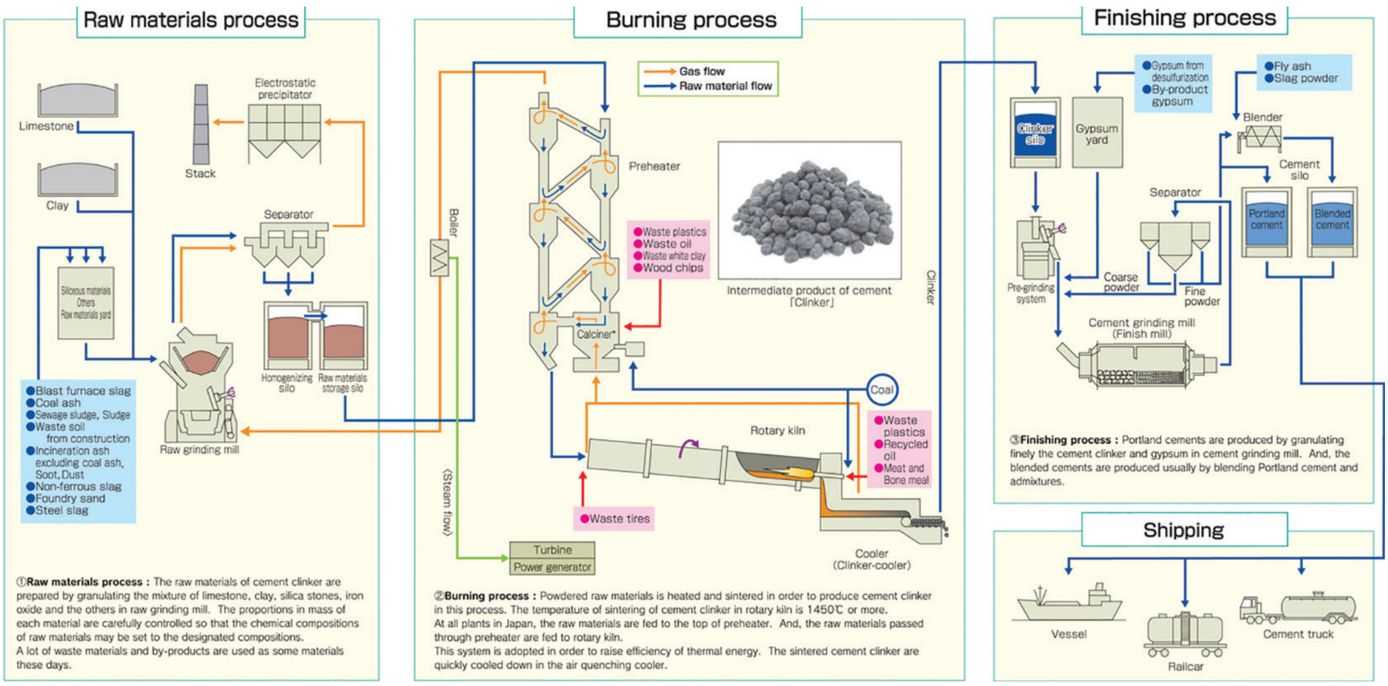


Figure 4: Detailed Cement Manufacturing Process[6]

The most common primary raw material (rock types) used in cement production is limestone. This could be augmented by clay, marl or shale, which supplies the bulk of the silica, alumina and ferric oxide. Other materials will be supplemented to the raw material such as sand, fly ash/pulverised fuel ash, or ironstone to achieve the desired bulk composition.

The limestone is mined and then transported to the cement manufacturing facility. Most South African sites have restoration schemes, where the topsoil removed during the initial mining is stored and then returned to the mine site to rehabilitate the site and restore it to close to its original state. These schemes promote biodiversity and environmental sustainability.

The limestone rock is then crushed into a manageable size. Based on the geology of the area and the chemical composition of the limestone, other ingredients may be added to the raw crushed limestone. Typical ingredients would include clay, shale, iron ore and ash. These are then mixed together in a dry homogeneous mix.

The blended raw materials are stored in a silo before being fed into the kiln. The silo stores several days' supply of material to provide a buffer against any glitches in the supply of raw material from the quarry.

To facilitate the mixing process, the raw meal will be preheated for a period of time before being introduced to the kiln. The kiln will very slowly process the raw meal at around 1 450°C. This causes a change in the chemical structure of the raw materials to produce a product commonly called 'clinker'. In theory, the cement producer can control the final composition of the clinker. In practice, however, clinker composition is largely determined by the compositions of the locally available raw materials that make up the bulk of the raw meal.

[6] Japan Cement Association: https://www.jcassoc.or.jp/cement/8img/e_01a_fig01.jpg. Accessed Jun 2022.

Some more additives like gypsum, slag or fly ash may be included to the clinker to produce the specific cement properties required. The gypsum controls the setting properties of the cement when water is added. The final clinker is then milled to a fine powder to produce the cement that is commonly known.

At the manufacturing facility, the final product may be stored locally or shipped in bulk. Some facilities may also have a bagging operation where the cement product is bagged into the 50 kg bags commonly used in South Africa.

Almost all cement manufactured in South Africa is used locally. Transportation costs associated with the delivery of the product to the final point of use is thus limited to local transport modes only.

Cement manufacturing has a direct impact on carbon emissions, since the chemical processes involve actually produce CO_2. Many companies intent on reducing carbon emissions will focus on optimising the manufacturing process to achieve this. Many innovations have already been introduced at various factories.

It is interesting to note that concrete naturally re-absorbs CO_2 from the atmosphere, so a good building design can act as a carbon capture store and have a positive effect on carbon emissions.

3. ENERGY EFFICIENCY IN CEMENT MANUFACTURING

Cement manufacturing is an energy-intensive process. Cement usage is an important ingredient in economic growth in South Africa, as it is elsewhere in the world. It is envisaged that cement manufacture cannot be substituted as yet and will increase in capacity for the foreseeable future. Hence, it behoves all stakeholders to improve energy efficiency in the cement manufacturing industry as it is a key enabler of economic growth.

Traditionally energy was cheap in South Africa. Manufacturers were only focused on production. Recent changes have forced manufacturers to start incorporating energy efficiency and energy security objectives in their business strategies and production planning. Figure 5 shows the key energy intensive processess in a typical manufacturing facility.

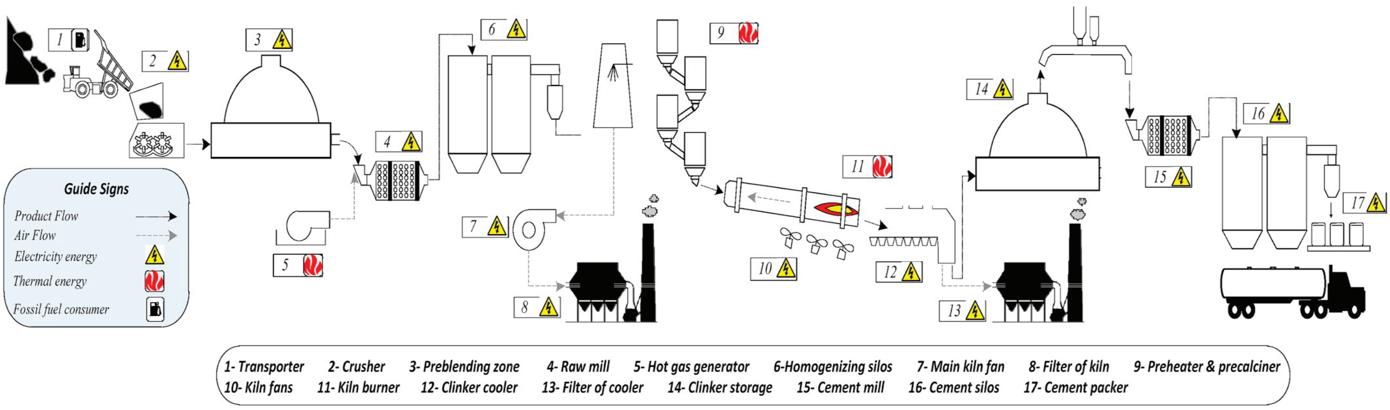


Figure 5: Energy Intensive Components of Cement Manufacturing[7]

In general, the thermal energy component is approximately 80% of total input energy in the plant. This focuses on the kiln burner and the pre-heater and pre-calciner. The rest of the energy is mainly electrical where the main electrical energy consumers are the mills and crushers. Large motors like kiln drives and fans and filter systems also consume a significant amount of electrical energy.

Table 1 gives a broad overview of the energy intensity of the various components within a cement manufacturing facility. It could be used to help facilities to identify focus areas for energy-saving opportunities.

[7] A Mokhtar, M Nasooti. A decision support tool for cement industry to select energy efficiency measures. Energy Strategy Reviews. 2020

Table 1: Overview of Energy Intensity of Components

Overview of Energy Intensity of Components				
#	Component	Electrical	Thermal	Fossil
1	Transporter			High
2	Crusher	High		
3	Pre-blending			
4	Raw mill	High		
5	Hot gas generator	Medium	Medium	
6	Homogenising silos	Low		
7	Main kiln fan	Medium		
8	Kiln filter system	Medium		
9	Pre-heater & pre-calciner		High	
10	Kiln fans	Medium		
11	Kiln burner		High	
12	Clinker cooler	Medium		
13	Cooler filter system	Medium		
14	Clinker storage	Low		
15	Cement mill	High		
16	Cement silos	Low		
17	Cement packer	Low		

Various technologies can be used to increase the efficiency of heating materials in the pre-calciner and kiln to form clinker. This reduces thermal energy consumption and associated CO_2 emissions. Today's international best practice energy use is 3.0–4.0 GJ/ton clinker (European Commission (BREF), 2013), while the theoretical minimum energy use is 1.85–2.80 GJ/ton clinker (varying with moisture content of the input materials).

Key technologies and techniques that help to reduce **thermal** energy use include:

- Use a dry-process kiln. These kilns utilise input materials with lower moisture content, so less heat is needed to evaporate water.
- Use a kiln with a pre-calciner and multistage pre-heater. This equipment allows the input materials to be dried using waste heat before they enter the kiln.
- Add mineralisers to the raw materials to reduce the temperature at which they convert into clinker.
- Operate the kiln with oxygen-enriched air.
- Use a grate clinker cooler, which is better at recovering usable excess heat than a planetary or a rotary cooler.

Electricity in cement manufacturing is primarily used for grinding raw materials, fuel and cement. In a dry kiln cement plant, electricity use is typically broken down as follows: 38% cement grinding, 24% raw material grinding, 22% clinker production including grinding of solid fuels, 6% raw material homogenisation, 5% raw material extraction, and 5% conveying and packaging.

Key technologies for reducing electricity consumption include:
- Replacing ball mills with high-pressure grinding rolls or vertical roller mills can reduce electricity demand from grinding by 50–70%.
- Heat recovery from kiln to generate electrical power.
- Installing variable speed drives (VSDs) on kiln motors.
- Installing speed drives on fan and filter systems.
- Improve grinding media in ball mills.
- Use bucket elevators rather than pneumatic material transfer systems where possible.

If the electricity is generated from fossil fuels, electricity efficiency can also reduce upstream emissions.

3.1 Plant Wide Opportunities

3.1.1 Energy Management Systems (EnMS)

Changing how energy is managed by implementing an organisation-wide energy management system is one of the most successful and cost-effective ways to bring about energy-efficiency improvements. Energy efficiency does not happen on its own. A well-structured EnMS supported by top management creates the platform for positive change and provides guidance for managing energy throughout the organisation.

Functioning EnMS ensure that energy-efficiency improvements do not just happen once, but rather are identified and implemented in an ongoing process of continuous improvement. Furthermore, without the backing of a sound energy management programme, energy efficiency improvements might not reach their full potential due to lack of a systems perspective and/or the support of proper maintenance and follow-up.

3.1.1.1 Development of an EnMS

The most common management opportunities are included in the implementation of EnMS. The key activities here would include inter alia:
- Top management demonstrating commitment by making resources available for the identification and implementation of energy-improvement opportunities.
- Assigning specific roles and responsibilities to personnel pertaining to the management of energy within the organisation.
- Identification of areas and machinery that consume significant amounts of energy.
- Development of relevant energy-performance indicators to monitor and track energy performance.
- Setting targets for improvement that can be achieved through implementation of identified energy-improvement projects.
- Ensuring that all personnel have been trained to operate machinery and manage processes in an energy-efficient manner.
- Evaluating and verifying energy savings following implementation of energy projects.

Implementation of an EnMS allows for the systematic management of energy throughout the organisation. It involves activities in three critical areas, namely people, technology and data. It is also a cyclic process that follows the 'Plan-Do-Check-Act' process:
- **Plan:** Establish the context, data, objectives and processes necessary to deliver results.
- **Do:** Implement the processes.

- **Check:** Monitor and measure energy performance and the processes against the policy, objectives, energy targets, legal and other requirements, and report results.
- **Act:** Take actions to continually improve energy performance and the EnMS.

Figure 6 shows the savings that were achieved by early adopters of EnMS. The 9 companies were medium and large companies from metal processing, chemicals, automotive, construction material and power generation sectors in Egypt, North Macedonia, South Africa and Turkey (UNIDO, 2021). EnMS-unique-enabled savings here would include no-cost and low-cost opportunities that did not require capital expenditure planning. They were typically behavioural changes that were identified during the initial stages of EnMS implementation.

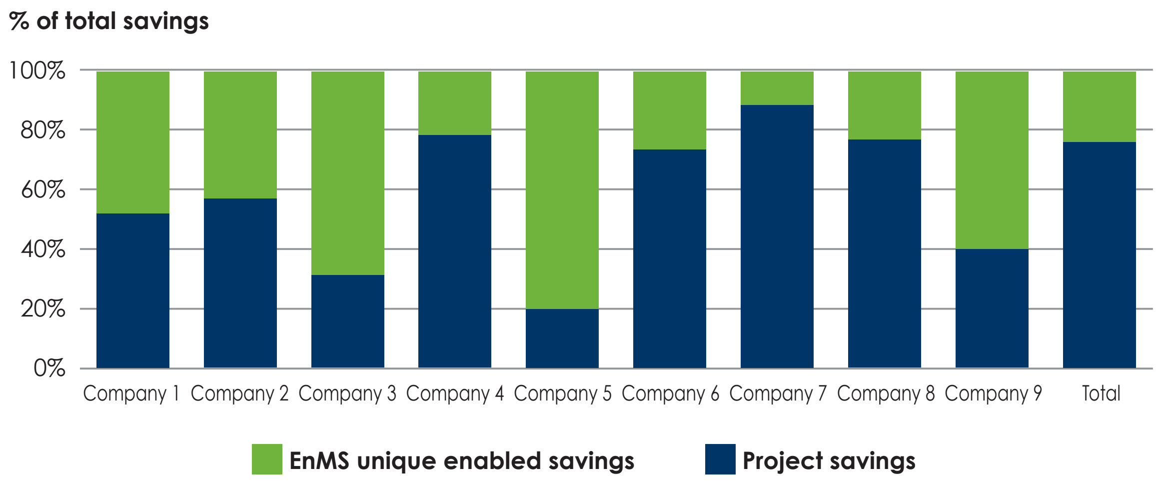


Figure 6: Energy Savings Achieved Through EnMS Implementation[8]

Other opportunities for improving energy performance from a process optimisation perspective have been identified from anecdotal evidence from interviews with key personnel in the industry.

3.1.1.2 Management of Personnel

Improvement opportunities related to no-cost energy savings invariably involve behaviour change of personnel. Depending on the type of opportunity, this could include operational, maintenance or administrative personnel.

Personal interviews conducted with selected local manufacturers have revealed the importance of having the right personnel. Some of the key considerations to enable a path towards sustainability and energy-performance improvement include:

- To foster a culture of continuous learning and improvement.
- To enable a growth (career) path for personnel within the company to improve staff retention.
- To create an inclusive culture where management and personnel become jointly accountable for energy-performance improvement.
- Develop an energy team that will drive and maintain the energy system.
- Personnel at all levels should be aware of energy use and company objectives for energy-efficiency improvement.
- Energy-efficiency programmes with regular feedback on staff behaviour, such as reward systems, have had the best results. Though changes in staff behaviour (such as switching off lights or closing windows and doors) often save only small amounts of energy at one time, taken continuously over longer periods they can have a much greater effect than other more costly technological improvements.

[8] UNIDO EnMS

3.1.1.3 Energy Performance Monitoring

The old adage "you can't manage what you can't measure" is applicable here. Energy-performance measurement and monitoring is required for the EnMS to be successful. It is also necessary to ensure early detection of system deviations from the most optimal operating conditions. In addition to energy performance, it could also lead to improved product quality.

Many companies have already implemented an EnMS. In almost all cases, they can still be improved. Typically, energy and cost savings are around 5% or more for many industrial applications of process control systems. These savings apply to plants without updated process control systems.

3.1.2 Maintenance

Preventative maintenance includes training personnel to be attentive to energy consumption and efficiency. While many processes in cement production are primarily automated, there still are opportunities that require minimal training of employees to increase energy savings. Also, preventative maintenance (e.g. for the kiln refractory) can also increase a plant's utilisation ratio, since it has less downtime over the long term and improves process stability.

Best practices
Varying levels of preventive maintenance at each facility make it difficult to predict, but savings of between 3 to 5 kWh/ton of clinker have been achieved.

Savings opportunities
- Training of personnel in first-line maintenance, and
- Implementing condition-based maintenance.

3.1.3 Motor Systems Optimisation

Electric motors account for more than 70% of all electrical energy consumption in industrial systems. In the cement industry, motors are responsible for the majority of electricity consumption. Motors are used to drive fans and blowers, rotate the kiln, transport raw materials and finished products, and most importantly, to grind raw material and cement. More than 500 to 700 motors of various capacities can be used in a single cement plant (E Worrell, 2008).

Hence, motor optimisation is an important course of action in any manufacturing facility. Motors, however, do not operate in isolation. They are connected to the electrical network on one end and a mechanical load and application on the other end. The motor system in its entirety exists to fulfil a function in the production process.

3.13.1 The Systems Approach

The best way to improve a motor system is to view it as a whole system. Figure 7 shows the functional diagram of a motor system. It consists of a power source, the motor controls, the actual motor itself, a transmission, the mechanical load application, and finally the actual function of the motor in the production system itself.

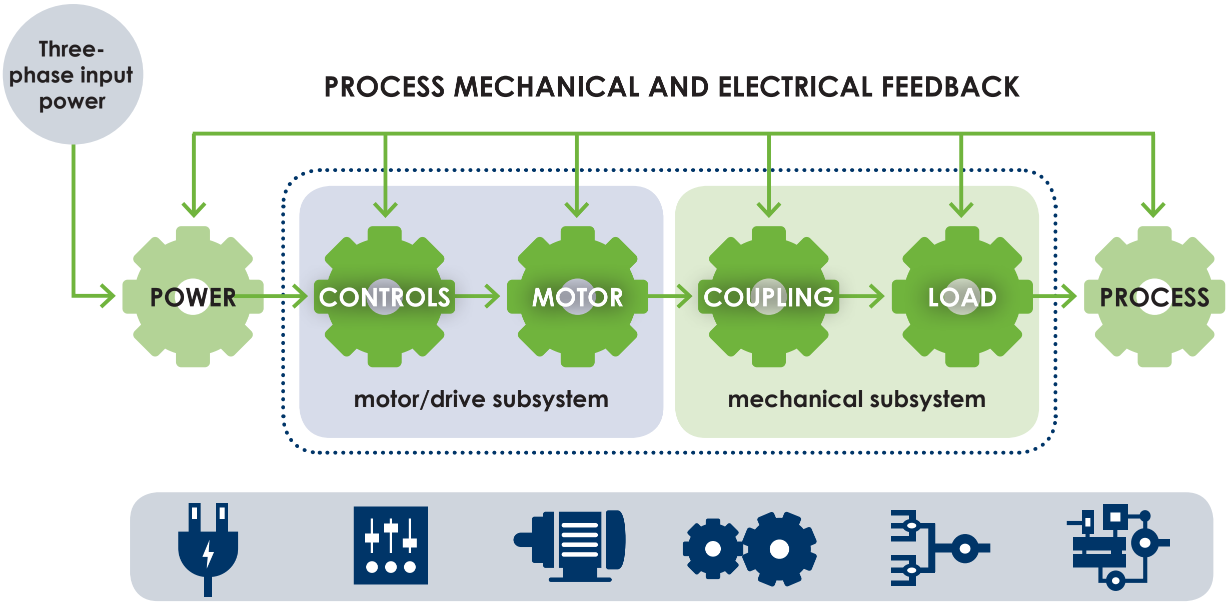
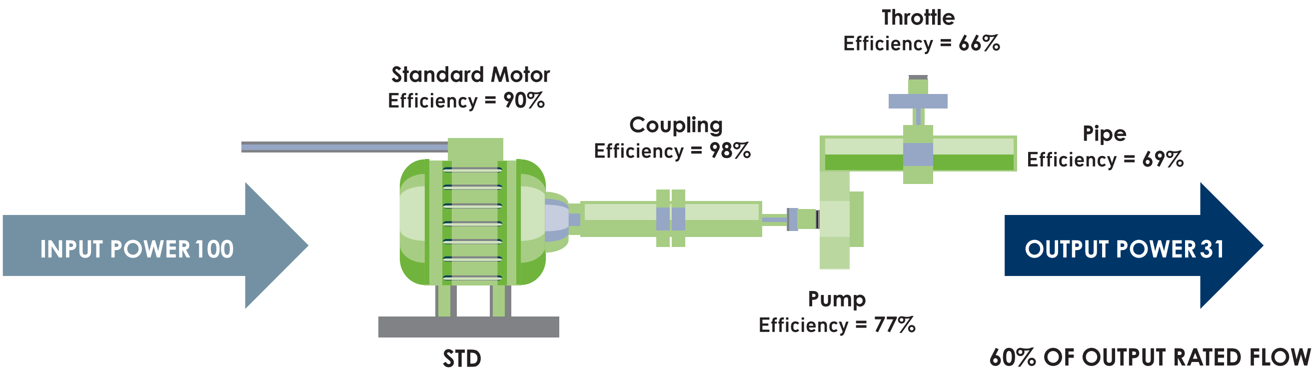


Figure 7: The Motor System

Conventional wisdom suggests that the easiest way to improve a motor system is to install a more efficient motor. This is very rarely the case. Figure 8 shows the typical system efficiency for a motor system connected to a pump that is transporting some fluid to a production process. The motor itself has good efficiency of 90%, but the overall system efficiency is only 31%. This effectively means that 69% of the total electrical energy input is being wasted in the system.

Improving the motor efficiency from 90% to 95% can be achieved by installing a new technology, high-efficiency motor. However, the system efficiency in this case will only improve to 32%. Improving other components in the motor system will lead to much better improvements with a superior return on investment.



System efficiency is the product of the efficiencies of the individual components

$$\text{Efficiency } (\eta) = \eta_{motor} * \eta_{coupling} * \eta_{pump} * \eta_{throttle} * \eta_{pipe}$$

$$= 90\% * 98\% * 77\% * 66\% * 69\% = 31\%$$

Figure 8: Typical Motor System Efficiency[9]

[9] Source: de Almeida, et al

In this example, the following improvements were made at a cost equivalent to the high-efficiency motor (HEM):
• Replace throttle control with VSD (eliminate throttle efficiency of 66%).
• Install more efficient pump (improve to 85%).
• Cleaning blockages from piping (improve to 90%).

The system efficiency has improved to 67.5%. In this instance, the losses have been virtually halved, saving 30% of electrical energy consumption, compared with a straight HEM replacement where the electrical energy savings only improved by < 2%.

This systems approach is thus recommended for the analysis of motor systems in any industrial facility including textile plants. Furthermore, it is also recommended to start the assessment by understanding the process needs first.

A simple methodology to follow to assess a motor system:
a) Develop a list of all motors at the plant. Quantify their usage and estimate the annual energy consumption.
b) Prioritise the motors that consume the most energy, or that break down often, or that are ready for replacement or upgrade.
c) For the prioritised list of motors:

- Understand the function of the motor system. What purpose does it fulfill in the production process?
- What is the actual energy required by the process?
- Assess each component of the motor system for improvement opportunities.
- Review the maintenance history of the motor.
- Build a business case for optimisation based on potential energy savings against project implementation costs. Include non-energy benefits like maintenance reduction or productivity improvements.
- Implement if viable and monitor the system to determine actual savings post implementation.

3.1.3.2 Motor Management

Motor Management Plan
A motor management plan is an essential part of a plant's energy management strategy. Having a motor management plan in place can help companies realise long-term motor system energy savings and will ensure that motor failures are handled.

Motor Replacement
As demonstrated with the systems, motor replacement or upgrade is not usually considered as a first approach to improving energy efficiency. However, when a motor fails, it may be financially viable to replace with a high-efficiency motor. The failed motor will have to be replaced or repaired anyway. The energy savings will thus have to be offset only against the extra cost of replacing with a high-efficiency motor.

Motor Maintenance
Ensure that motors are maintained and operated correctly:
• Keep area around motor clean to allow fan to cool motor and heat to be dissipated from the exterior fins of the motor.
• Dust from raw meal or finished cement that accumulate on the motor act as a thermal insulator, and may cause the motor to operate at a higher temperature, thereby reducing its lifespan.

3.1.3.3 Load Application: Pumps and Fans

The control of the mechanical load application often represents the most practical and beneficial way to improve energy efficiency of a motor system. The majority of larger pumps and fans in a cement plant will be centrifugal pumps. These conform to the affinity laws providing specific relationships between the speed of the drive motor, fluid flow, fluid pressure, and fluid power. Reducing the speed of a drive motor will reduce the flow and pressure as well as the power requirement but in a much higher proportion.

Identify motor systems that represent good opportunities for improvement. It is recommended to engage a technically competent person to assess each system and recommend appropriate energy-saving strategies. The following should be considered:

- Multiple pumps in parallel.
- Multiple fans in parallel.
- Fans or pumps that operate at part load and cycle on and off fairly regularly during normal production.
- Fans or pumps where the production has dramatically increased or decreased since commissioning.
- Fans or pumps that fail often.

3.2 Process Opportunities

Process opportunities can divide the cement process into three distinct phases. These phases will be reviewed to identify the most common energy-saving opportunities.

Table 2: Phases of Cement Manufacture

Raw material preparation	Clinker production	Final product preparation
• Mining • Crushing • Pre-blending • Grinding • Blending	• Pre-heating • Firing • Cooling • Clinker storage	• Final milling • Storage • Packaging • Distribution

3.2.1 Raw Material Preparation – Mining

Cement plants are typically located close to naturally occurring materials like limestone, marl or chalk, which are extracted from quarries, providing calcium carbonate ($CaCO_3$). Very small amounts of materials such as iron ore, bauxite, shale, clay or sand may be needed to provide the extra mineral ingredients, iron oxide (Fe_2O_3), alumina (Al_2O_3) and silica (SiO_2) necessary to produce the desired clinker.

For open-pit mining operation, heavy-duty mining equipment are the major uses of energy. In most cases these are diesel powered. There may also be some electrical energy consumption, especially where primary crushers are located on the mining site.

In shaft mining operations there will be additional electricity consumption for haulage of material to the surface. Air conditioning and pumping of drainage water will also add to the energy consumption.

Savings opportunities

- Plan the site excavation to maximise the yield and minimise the haulage required.
- Operate haulage trucks efficiently. This would include monitoring driver behaviour through fuel to hours ratio.
- Maintain haulage trucks. Regular maintenance as per original equipment manufacturer or as determined by maintenance personnel.
- Minimise distance travelled. Planning operations to minimise distances travelled by haulage trucks.
- Slow down conveyors with large motors. Use a VSD to slow down large motors. Repeated frequent starting of large motors will reduce the motor's life span.
- Switch off conveyors when not required. Smaller or shorter conveyors with smaller motors may be safely switched off without causing too much reduction in life span.

3.2.2 Raw Material Preparation – Crushing

The large rocks from the quarry will be crushed down to approximately 10 cm in diameter through a series of crushers or mills. Traditionally, ball mills and jaw crushers were used but these are not as efficient as some of the newer crushers.

In the cement industry, the primary crushing of raw materials takes place in single- or twin-rotor hammer crushers (mills) or impact crushers. The use of jaw crushers in cement plants has been decreasing and are nowadays mainly used in small cement plants in combination with roll or gyratory crushers for the crushing of hard and abrasive materials (Chatterjee, 2004).

Best practices
The average power consumption for crushing is estimated to range between 0.5 and 0.9 kWh/ton[10] of raw material. The gyratory crusher has a power consumption of 0.34–0.50 kWh/ton of raw material, and is currently recognised as best available technology. (Chatterjee, 2004).

Savings opportunities
- Grading the crushing process. Select the optimum sizing for each crusher in the crushing process to minimise overall energy consumption.
- Installing efficient crushing machines. Replacing old inefficient ball mills and jaw crushers is capital intensive and must be justified by saving in energy; it should be considered at end of life or major failure.
- Installing modern gravimetric feeders and scales. More accurate flow control and measurement of quantities will improve product quality and reduce waste.
- Upgrading to high efficiency motors. (Section 3.1.3)

3.2.3 Raw Material Preparation – Pre-blending

Crushed raw material will often be stockpiled for later use. This is to allow the energy-intensive processes that follow to be scheduled optimally to maximise throughput at minimum operating cost and time. This process usually requires electrical energy or diesel, depending on the location and conveyancing methods used.

Best practices
Best practices for the pre-blending of raw materials are considered a longitudinal store system with a bridge scraper or bucket wheel reclaimer, or a circular store system with a bridge scraper reclaimer.

The energy use is estimated at 0.34 kWh/ton raw material. (E Worrell, 2008)

Savings opportunities
- Optimise the storage and retrieval of raw material.
- Use mobile rotary stacker reclaimers.
- Optimise motors (Section 3.1.3).

3.2.4 Raw Material Preparation – Grinding & Blending

After crushing, the raw materials are mixed and milled together to produce 'raw meal'. To ensure high cement quality, the chemistry of the raw materials and the subsequent raw meal is very carefully monitored and controlled.

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[10] Chatterjee, A.K., 2004. Materials Preparation and Raw Milling. In: Bhatty, J.I., M.F. MacGregor, S.H. Kosmatka, editors, 2004. Innovations in Portland Cement Manufacturing. SP400, Portland Cement Association (PCA), Skokie, Illinois, U.S.A., 2004, 1404 pages

To produce a good quality product and to maintain optimal and efficient combustion conditions in the kiln, it is crucial that the raw meal is completely homogenised. Quality control starts in the quarry and continues to the blending silo.

Best practices

Mechanical conveyors use less power than pneumatic systems. Vertical roller mills and roller presses are more efficient than ball mills.

Table 3: Specific Energy Consumption for Various Mills[11]

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

Savings opportunities

Installing High-Efficiency Mills

Traditional ball mills used for grinding certain raw materials (mainly hard limestone) can be replaced by high-efficiency roller mills, by ball mills combined with high-pressure roller presses, or by horizontal roller mills. The use of these advanced mills saves energy without compromising product quality.

A roller mill for raw material grinding will increase throughput, flexibility, raw meal fineness and reduce electricity consumption. Rollers are pressed down using spring or hydraulic pressure while hot gas is supplied during grinding for raw material drying. These air-swept vertical roller mills can handle materials containing up to 20% moisture while ball mills can handle moisture levels of about 12% (Chatterjee, 2004).

Vertical roller mills have 10–20% higher capital costs when compared to ball mills. The use of roller presses is limited to the grinding of non-abrasive materials with low moisture content. Energy use can be 50% lower when compared to ball mills. According to Chatterjee (2004), by using roller presses in combination with a Vseparator, energy requirements can be as low as 14 kWh/ton raw material.

Vertical roller mills, for a medium raw material hardness and medium fineness product, require less energy than 9 kWh/ton. An additional advantage of the inline vertical roller mills is that they can combine raw material drying with the grinding process by using large quantities of low-grade waste heat from the kilns or clinker coolers (Venkateswaran and Lowitt, 1988).

Conversion to Mechanical Conveyors

Replacing pneumatic conveyors with high capacity bucket elevators for raw material transfer to the preheaters and the blending silos can reduce power consumption by an estimated 1.9 kWh/ton raw material. It is cost-effective when replacement of conveyor systems is needed to increase reliability and reduce downtime.

Using Fluidised Conveyancing Lines

The bulk material is supplied through feeding devices (i.e. pump, pressure vessel) to a fluidised conveying (FLC) line. The conveying gas coming from the compressed air generator is divided into two streams; one gas stream is supplied at the entrance of the FLC pipe, while the other gas stream travels in parallel to the FLC pipe in a so-called aeration pipe,

[11] Cement Sustainability Initiative of WBCSD. Technology Paper 22: Existing and Potential Technologies for Carbon Emissions Reductions in the Indian Cement Industry. 2013

supplying air at several points to the FLC pipe. In this way, the transferred material is raised from the bottom of the pipe and flows into the gas stream in a similar process to an air-activated gas conveyor. The air flow needs to be controlled to avoid blockages. Energy savings are estimated at 1.0 kWh/ton raw material.

Optimising Raw Meal Blending (Homogenising) Systems

On-line analysers for raw mix control are an integral part of the quality control system. Improved raw material blending may reduce heat requirements by 0.02 MBtu/ton clinker and power requirements by 0.73 kWh/ton raw material, while production could also increase by 5% (Hollingshead and Venta, 2009).

Separate Raw Material Grinding

Different raw materials are characterised by different grindability. Materials that are harder to grind, such as sand and blast furnace slag, require higher amounts of energy to reach the desired particle fineness and decrease the throughput of the combined material grinding system.

Separate raw material grinding will allow a more precise particle size distribution of different raw meal components. This measure is considered financially sensible when high rates of hard-to-grind materials (i.e. slag) are used.

Gravity-Type Silos

Modern plants use gravity-type homogenising silos (or continuous blending and storage silos), reducing power consumption. In these silos, material funnels down one of many discharge points, where it is mixed in an inverted cone. Gravity-type silos may not give the same blending efficiency as air-fluidised systems.

For older systems, silo retrofit options are cost-effective when the silo can be partitioned with air slides and divided into compartments that are sequentially agitated, as opposed to the construction of a whole new silo system. Most older plants use compressed air to agitate the powdered meal in so-called air-fluidised homogenizing silos (using 1–1.4 kWh/ton raw meal).

Raw Meal Process Control

Vertical roller mills are prone to trip out on vibration alarms. Operation at high throughput makes manual vibration control difficult. Frequent trips will mean that the motor cannot be started again until the windings cool. A model predictive multivariable controller maximises total feed while maintaining a target residue and enforcing a safe range for trip-level vibration. In addition, the motor could be fitted with a soft starter or VSD if it becomes problematic at high throughputs.

High-Efficiency Classifiers/Separators

A recent development in efficient grinding technologies is the use of high-efficiency (third-generation) classifiers or separators. Classifiers separate the finely ground particles and recycle coarse particles back to the mill. High-efficiency classifiers can be used in both the raw materials mill and in the finish grinding mill.

High-efficiency classifiers have improved air recirculation and separate centrifugal movement. The material stays longer in the separator, leading to more precise separation, thus reducing overgrinding. Electricity savings from implementing high-efficiency classifiers are estimated at 8% of the specific electricity use. Some case studies have shown a reduction of 2.5–3.4 kWh/ton raw material.

3.2.5 Clinker Production – Pre-heating and pre-calcining

Pre-heating: Hot exhaust gases coming from the kiln preheat the powdered raw meal before it enters the kiln. A preheater consists of a series of cyclones through which the raw meal is passed by swirling hot flue gases in the opposite direction of the material flow. In these cyclones, thermal energy (heat) is recovered from hot flue gases with the benefits that the raw meal is preheated, the efficiency of the process is improved and less fuel is needed. Depending on the raw material moisture content and heat recovery requirements, a kiln may have up to six stages of cyclones, with increasing heat recovery at each extra stage.

Pre-calcining: Calcination is the transformation of limestone into lime. Part of the high-temperature reaction in modern installations takes place in a 'precalciner', a combustion chamber at the bottom of the preheater above the kiln, and partly in the kiln. Here, the chemical decomposition of limestone, generating typically 60% of total CO_2 emissions of the cement manufacturing process occurs. Fuel combustion generates the rest of the CO_2.

Pre-calciner technology is a more recent development. A second combustion chamber has been added between the kiln and a conventional pre-heater that allows for further reduction of kiln fuel requirements.

Saving opportunities

Preheater Shell Heat Loss Reduction

The outer part of the upper preheater vessels and the cooler housing can also be insulated. The energy savings are estimated at about 17 kBtu/ton clinker and at an investment cost of $0.30/ton (Hollingshead and Venta, 2009).

Low Pressure Drop Cyclones for Suspension Preheaters

Cyclones are a basic component of plants with pre-heating systems. The installation of newer cyclones in a plant with lower pressure losses will reduce the power consumption of the kiln exhaust gas fan system.

3.2.6 Clinker Production – Pyro-processing (Firing)

Clinker production is the most energy-intensive stage in cement production, accounting for over 90% of total industry energy use, and virtually all of the fuel use. Clinker is produced by pyro-processing in large kilns. These kiln systems evaporate the inherent water in the raw meal, calcine the carbonate constituents (calcination), and form cement minerals called clinker.

Most modern kilns are long dry rotary-type kilns. Pre-calcined meal enters the kiln at temperatures of around 1 000°C. Fuel (such as coal, petroleum coke, gas, oil and alternative fuels) is fired directly into the rotary kiln at up to 2 000°C to ensure that the raw materials reach material temperatures of up to 1 450°C. The rotary kiln (a brick-lined metal tube 3–5 metres wide and 30–60 metres long) rotates about three to five times per minute, and the raw material flows down through progressively hotter zones of the kiln towards the flame. The intense heat causes chemical and physical reactions that partially melt the meal into clinker.

There are older, much less efficient technologies, for example wet kilns into which raw material is fed as wet slurry and not as powder (as is the case in dry kilns). However, wet kilns have almost been phased out because they require about 36% more energy to evaporate the water.

Saving opportunities

Process Control & Management Systems

Heat from the kiln may be lost through non-optimal process conditions or process management. Automated computer control systems may help to optimise the combustion process and conditions under a variety of fuels. Improved process control will also help to improve the product quality and grindability, e.g. reactivity and hardness of the produced clinker, which may lead to more efficient clinker grinding.

In cement plants across the world, different systems are used, marketed by different manufacturers. A model predictive control system was installed at a kiln in South Africa in 1999, reducing energy needs by 4%, while increasing productivity and clinker quality. The payback period of this project was estimated at eight months (Martin and McGarel, 2001a).

Mineralised Clinker

Mineralisers and fluxes are substances used to improve the raw mill combustion process. Mineralisers (like fluorine) promote the formation of clinker, while fluxes (like alumina or iron oxide) lower the viscosity of the melt, thereby lowering the temperature at which the sintering starts taking place to form clinker. This results in reduced fuel consumption, lower emissions, and even shorter residence times in the kiln.

Indirect Firing

In older plants, coal and primary air is directly fed into the kiln and combusted. This limits the ability to control the combustion process and burn profile along the kiln. This may lead to premature aging of the refractory in certain hotspots along the kiln wall.

In modern cement plants, indirect fired systems are most commonly used. Here the primary and secondary air can be more controlled allowing the operator to optimise the combustion profile along the kiln, reducing fuel usage, reducing emissions and allowing for flexibility to adjust the fuel mixture.

Mixing Air Technology

Optimisation of the air stream into the kiln can affect the burnability, allowing for a more complete and effective combustion of fuel and oxygen. Many different suppliers are available with different types of air injection systems or mixing air technology. The injection of a high-pressure air stream into the kiln results in improved mixing of the stratified gas layers created within the kiln.

The result is reduced fuel use, lower emissions and improved kiln stability. The electricity consumption will increase marginally to power the system, but the burner fuel costs will be reduced significantly.

Seals

Seals are used at the kiln inlet and outlet to reduce false air penetration, as well as heat losses. Seals may start leaking, increasing the heat requirement of the kiln. Regular inspection is recommended to control leaks. The payback period for improved maintenance of kiln seals is estimated to be six months or less.

Kiln Shell Heat Loss Reduction

Heat losses through the kiln shell can be significant. Heat loss can be minimised by improving insulation, but more importantly by improving the refractory lining the kiln. The use of improved kiln refractories may also lead to improved reliability of the kiln and reduced downtime, reducing production costs considerably, and reducing energy needs during start-ups.

Kiln Drives

These are usually very large motors (1 000kW or more). Synchronous motors offer a distinct advantage in overall efficiency in comparison to induction motors. Using high-efficiency motors to replace older motors instead of re-winding old motors, may also reduce overall energy consumption. It is important that transmissions, bearings and other mechanical devices be maintained properly. A small deviation from optimum can have a large absolute effect on motor energy consumption.

Adjustable Speed Drive for Kiln Fan

Where kiln fans do not operate at full load, installing a VSD to control flow may result in reduced energy consumption. It will also extend the life of the fan and reduce maintenance costs, as the very high start-up currents are avoided. It also allows for more precise temperature control that could improve clinker production.

Dry Process Conversion to Multi-Stage Preheater Kiln

Older dry kilns may only preheat in the chain section of the long kiln, or may have single- or two-stage preheater vessels. Some older long dry kilns may not have any preheater vessels installed at all, resulting in low-efficiency heat transfer, and consequently higher energy consumption. Installing multi-stage suspension preheating (4, 5 or 6) will improve the overall kiln efficiency. The length of the kiln can also be reduced significantly.

Increase the Number of Preheater Stages

The addition of a preheater stage will not always result in system energy savings. The optimum number of stages is determined by the moisture content of the fuel and raw materials that need to be dried. When the raw materials' moisture content is above 8%, the drying heat requirements are high and it is more cost- and energy-effective to operate the kiln with a four or even a three-stage preheater.

Installation or Upgrading of a Preheater to a Preheater/Pre-calciner Kiln

An existing preheater kiln may be converted to a multi-stage preheater pre-calciner kiln by adding a pre-calciner and, when possible, an extra preheater. The addition of a pre-calciner will generally increase the capacity of the plant, while lowering the specific fuel consumption and reducing thermal nitrogen oxide (NOx) emissions. Fuel savings will depend strongly on the efficiency of the existing kiln and on the new process parameters.

Heat Recovery for Power Generation

Waste gases that contain significant amounts of heat are discharged to the atmosphere from the kiln exit, the clinker cooler and the kiln pre-heater. Heat recovery for cogeneration can result in significant electricity savings of up to 30% and primary energy savings of up to 10%. Not all systems are suitable for direct power generation. In some cases, a small steam turbine may need to be installed while others may make use of refrigerants in an indirect low-heat application.

3.2.7 Clinker Production – Cooling & Storage

From the kiln, the hot clinker is cooled from 1 000°C to about 100°C, using large quantities of air, part of which can serve as combustion air. Coolers are essential for the creation of the clinker minerals which define the performance of the cement. In this process, the combustion air is preheated, thereby minimising overall energy loss from the system. Clinker is usually used on site but can be transported by truck, train or ship to other grinding plants.

After cooling, the clinker can be stored in the clinker dome, silos, bins or outside. The material handling equipment used to transport clinker from the clinker coolers to storage and then to the finish mill is similar to that used to transport raw materials (e.g. belt conveyors, deep bucket conveyors, and bucket elevators).

Saving Opportunities

Conversion to Efficient Clinker Cooler Technology

The main types of coolers used for the cooling of clinker include shaft, rotary, planetary, travelling (second generation) and modern reciprocating grate coolers (third generation). Old shaft and rotary coolers are very rare nowadays.

The advantages of the grate cooler are its large capacity (allowing large kiln capacities) and efficient heat recovery (the temperature of the clinker leaving the cooler can be as low as 83°C, instead of 120–200°C). Grate coolers recover more heat than do the other types of coolers. For large capacity plants, grate coolers are the preferred equipment.

Optimisation of Heat Recovery/Upgrade Clinker Cooler

The clinker cooler drops the clinker temperature from 1 200°C down to 100°C. The most common cooler designs are of the planetary (or satellite), traveling and reciprocating grate type. All coolers heat the secondary air for the kiln combustion process and sometimes also tertiary air for the pre-calciner. Improving heat recovery efficiency in the cooler results in fuel savings, but may also influence product quality and emission levels.

Heat recovery can be improved through reduction of excess air volume, control of clinker bed depth and new grates such as ring grates. Control of cooling air distribution over the grate may result in lower clinker temperatures and high air temperatures. Additional heat recovery results in reduced energy use in the kiln and pre-calciner, due to higher combustion air temperatures.

3.2.8 Finishing – Milling & Storage

Around 4–5% gypsum is added to clinker to control the setting time of the final cement. The cooled clinker and gypsum mixture is ground into a grey powder called Ordinary Portland Cement or can be ground with other mineral components to produce, for example, Portland Composite Cements. Traditionally, ball mills have been used for grinding, although more efficient technologies are available and in use already.

Most of the savings opportunities identified in Section 3.2.4 will be applicable to this section. Some of the process parameters might be different though.

3.2.9 Finishing – Packaging & Distribution

Packaging is a small part of the energy consumption of cement manufacturing. It is mainly electrical energy consumption. Typical consumption for packaging is 0.65 kWh/ton[12] (S Prakasan, 2019).

Savings opportunities

- Switch off lights and machinery when not in use, and
- Optimise compressed air use (Section 3.3.4).

3.3 Utilities

3.3.1 Lighting

Lighting usually represents a quick and easy opportunity to reduce energy consumption. It is also quite visible and creates immediate awareness. In many cases, the lighting level can be improved with more efficient lamp replacements, thereby improving morale and productivity. This is an important non-energy benefit of energy-saving opportunities. In addition to the lamp replacements, it is also essential that the following operational improvements be included:

- Determine the need and compliance level required:
  - » Illumination level (how much light is actually needed),
  - » Colour requirements (colour temperature and colour rendering index),
  - » Quality requirements (glare, shadows), and
  - » Duration of the lighting (how many hours per day).

Compliance lighting levels are described by South African standards for various work areas and work surfaces. These are listed in the Facilities Regulations incorporated into the Occupational Health and Safety Act of South Africa. Many suppliers will offer no-cost or low-cost lighting assessments and will produce a report detailing recommended lighting to meet compliance requirements.

Best practices

It is estimated that conversion of lighting to LED equivalents will yield savings of 0.30 kWh/ton (A Mokhtar, 2020).

[12] S Prakasan, S Palaniappan, R Gettu. Study of Energy Use and CO_2 Emissions in the Manufacturing of Clinker and Cement. Journal of The Institution of Engineers (India) Series A. 2019

Lighting Control

- Use natural lighting where possible.
- In many instances in large open factories, there is a single switch to light the entire work space. Consider splitting circuits to only allow the correct amount of lighting. For example, at an operational area site the security cubicle is situated on the main factory floor. Because there is no separate light switch, the entire factory remains unnecessarily lit at night, just to enable lighting at the security cubicle.
- Automate lighting in seldom-used areas. For example, install motion sensors in warehouses, walkways, stairwells and toilets. Install light sensors for outdoor security lighting so that these are automatically switched on under low light conditions.

Lamp Replacement

Only lamps that are operated for a large number of hours per year should be considered for replacement.

- Replace old incandescent lamps in offices with new modern LED.
- Replace high-power discharge lamps in factories with LED or compact fluorescent equivalent.
- Replace halogen floodlights used for security with LED equivalent.
- Existing fluorescent lamps should only be replaced when they fail.

3.3.2 Electrical Network

3.3.2.1 Transformer Optimisation

Typical losses in a transformer are approximately 5%. This is a function of the magnetic circuit incorporated into transformer design. However, there ways to improve this slightly.

- Replacing oil transformers with resin cast transformers. Increase reliability, reduce maintenance and risk of failure.
- For oil transformers, maintain oil as per manufacturer recommendations.
- Operate transformers as close to nominal voltage as possible.
- Use the correct cable sizes to reduce voltage drop along cables.

3.3.2.2 Power Quality

Operating the electrical network at the optimal electrical parameters will assist in energy-efficient operation. It is recommended to use a qualified technical person to assist with power quality to ensure all safety standards are adhered to.

System Voltage and Waveforms

- Voltage: Ensure that the actual system voltage is maintained nearest to the system.
- Voltage unbalance: For three-phase supplies try to maintain a voltage unbalance of < 1.5%. This will limit excess heating of motors and prolong the lifespan.
- Harmonics: Ensure that harmonic distortion is kept to a minimum and within the specifications as determined by NRS 048 (power quality standard for South Africa).

3.3.2.3 Power Factor

This is a common problem in many manufacturing industries including textile facilities. Optimising power factor can extend the life of electric motors. Although not essentially an energy-saving strategy, power factor optimisation offers good electrical cost savings, and in most cases, will extend the life of electric motors.

It is recommended to contract a suitably qualified person to conduct a power factor review.

3.3.3 Fuel Optimisation

Coal is the most widely used fuel in the cement industry and in South Africa as well. Preparation of the fuel is an essential part of the combustion. In most South African power stations, the coal is pulverised and fed into the boiler as a fluidised bed to obtain the maximum heat transfer in the combustion process.

Similarly, preparation of the coal for a cement kiln is also important and may include crushing, grinding and drying. Vertical roller mills have become very common in the cement industry for crushing coal. Hot gases from the kiln may also be passed through the milling process to dry out the coal.

Electrical energy costs will increase slightly, but this will be more than offset by the reduction in input fuel (coal).

3.3.4 Compressed Air

Compressed air is a common utility in many plants. It is often misconstrued that because it is only air, it is free. This is often the most expensive form of energy in use in a plant. A unit of energy contained in compressed air would typically require seven units of electrical input energy into the compressor. In simple terms, using compressed air as an energy source is seven times more expensive than electricity. Conservation of compressed air can thus be a significant energy-saving opportunity.

Match Supply to Demand
Understand the requirements for compressed air from a process perspective and then match the supply of compressor (and air receiver) to the demand. Here, peak demand and average demand requirements need to be taken into account as well as future expansion.

Operating Multiple Compressors
- Switch off the compressed air system when not required – this is a simple but often ignored strategy. The compressors are left on over the weekend or at night because either nobody has been instructed to switch them off, or because personnel are not aware of the cost of operations. Starting up the compressed air system 10–15 minutes before production starts is often sufficient to build up the required operating pressure in the system.
- Ensure that each compressor runs in the most economical way. Idling compressors (when there is no demand for air) still consume a lot of energy without any productive output.
- Compressors, in general, operate most efficiently when fully loaded. An unloaded compressor consumes approximately 35% of its rated power when in unloaded mode. A standby compressor will consume less than 5% of its rated power when in hot standby.
- Stage compressors such that each unit is only brought into operation when the preceding one has reached full capacity.
- When installed, always use the VSD compressor as the final trim in a staging-type operating methodology.

System Air Pressure
Use the pressure appropriate to the equipment in the system. Often times the pressure is increased when the pressure at point of use is insufficient to support production. This is usually because of another problem, like piping restrictions, water in piping, leakages, or incorrect air tool. These need to be addressed first before optimising system pressures. A reduction in system pressure of 1 bar will result in a saving of approximately 7% of compressor input power (Atlas Copco, 2015).

Repair Air Leaks
Air leaks represent the most obvious and most common form of optimisation. It is often ignored because personnel are unaware of the real cost of compressed air. In most industrial systems, compressed air leaks would represent from 10% up to 65% of all compressed air generation. Well-maintained systems will have leak rates of below 10%.

Regular inspection and repair should form part of the maintenance strategy for the plant. Walk through each branch of the distribution system, including the air-consuming applications and devices. Mark-up all leaks using a tag, and repair as soon as possible during maintenance. Leaks are usually simple to repair. Leaks in difficult-to-access places can be detected by using a special leak detector.

Stop Inappropriate Usage

Most personnel are not aware of the true cost of compressed air and often consider it free as it consists of air. In effect, the cost of 1 kWh of compressed air is equivalent to the cost of 7 kWh of electrical energy. Unnecessary use of compressed air should immediately be identified and stopped. Examples include:

- Using compressed air for cooling of production equipment.
- Using compressed air for cooling of personnel.
- Using compressed air for cleaning of work surfaces or work areas.
- Using compressed air for cleaning of personnel.
- Using compressed air in certain production processes where more energy-efficient alternatives are available. For example, using it for stirring/agitation in a dye vat, or using it to clean out the boiler room, or removing dust and fibres from a loom.

Optimise Piping

- Eliminate or isolate unused sections of the pipes.
- Ensure correct pipe sizing for volume of usage required.
- Undersized pipes can lead to higher pressure requirements and higher leakage losses. Larger pipe sizes will offer reduced losses but require higher capital costs.
- Slope pipes to drain points that are fitted with drain traps that will open to expel water when full.

Heat Recovery

Install heat recovery where appropriate and financially feasible. As much as 85% of all electrical input into a compressor will be converted to heat energy and wasted to the atmosphere. If a low temperature heat requirement is located near the compressor room, then consider the use of a heat recovery system for the compressor.

Other General Optimisation Opportunities

- Ensure that the compressor air intake is in the coolest possible place. This would often be outside the compressor house, i.e. in a shaded side. A reduction of 4°C in intake air could lead to approximately 1% power reduction in compressor consumption (Atlas Copco, 2015).
- Install air receivers at the point of intermittent use to limit the cycling of compressors. Air receivers generally allow for more stable operation of systems as they act as dampers to reduce short-cycling.
- Ensure that air treatment equipment is operating satisfactorily.
- Do not 'over treat' the air beyond the requirement of the end use.

3.4 Opportunities Summary

Table 4 shows a summary of typical energy-efficiency interventions and their potential energy savings and implementation cost. (A Mokhtar, 2020). This is based on the key energy-intensive processes identified in Figure 5 (refer to Section 3).

Table 4: Summary of Energy-Efficiency Measures and their Potential Savings

Measures and their potentials for saving					
List of measures in eemdb	**Elecrical saving kWh/t**	**Thermal saving gj/t**	**Investing cost $/t**	**Payback period (year)**	**Installation duration (month)**
Eifficient transport systems (elevator insead of air conveyor)	3.40	000	3.0	10.0	3.0
Raw mill blending systems	3.00	0.00	3.7	10.0	4.0
Process control vertical mill	1.55	0.00	1.0	2.0	3.0
High-efficiency roller mills	11.05	0.00	5.5	10.0	18.0
High-efficiency classifiers	5.55	0.00	2.2	10.0	12.0
Energy management and process control	4.00	0.00	1.0	10.0	3.0
High presure roller press	18.00	0.00	5.3	1.5	12.0
High efficiency classifiers in cement (product) mill	3.95	0.00	2.0	10.0	12.0
Improved grinding media in ball mills	4.00	0.00	0.5	8.0	1.0
High eficency motors (applying variable speed drive)	3.00	0.00	0.2	1.0	1.0
Efficient fans with variable speed drive	7.00	0.00	1.3	2.5	5.0
Optimization of compressed air systems	3.00	0.00	0.2	1.0	9.0
Efficient lighting (led)	0.30	0.00	0.3	3.0	1.0
Production of blended cements	(11.00)	2.15	0.7	3.0	2.0
Use of waste derived fuels (incl. tyres etc.)	0.00	0.60	1.9	1.0	3.0
Production of limestone cement	2.80	0.30	0.0	1.0	1.0
Production of low alkali cement	0.00	0.44	0.0	0.0	1.0
Use of steel slag in kiln process (clinker to cement ratio)	0.00	0.19	1.0	2.0	1.0
Preheater kiln upgrade to precalciner kiln	0.00	0.43	18.7	5.0	12.0
Long dry kiln upgrade to preheater/precalciner kiln	0.00	1.40	18.8	10.0	24.0
Older diy kiln upgrade to multi-stage preheater kiln	0.00	0.90	34.5	10.0	24.0
Convert to reciprocating grate cooler	(3.00)	0.27	2.9	1.5	12.0
Kiln combustion system improvements	0.00	0.30	1.0	2.5	2.0
Optimize heat recovery/upgrade clinker cooler	(2.00)	0.105	0.2	1.5	2.0
Seal replacement the kiln process	0.00	0.011	0.1	0.5	0.5
Love temperature heat recovery for power	27.50	0.00	3.3	30	12.0
High temperature heat recovery for power	22.00	0.00	3.3	30	12.0
Low pressure drop cyclones	2.55	0.00	3.0	100	9.0
Efficient kiln drives motors	2.50	0.00	0.3	3.0	5.0
Improved refractories material	0.00	0.50	0.3	1.0	1.0
Kiln shell heat loss reduction	0.00	0.365	0.3	1.0	1.0
Adjustable speed drive for kiln fan	6.10	0.00	0.2	2.5	5.0
Selecting raw material with lower friction coefficient	0.10	0.00	0.1	1.0	6.0
Selecting raw material with lower humidity	0.00	0.10	0.1	1.0	6.0
Selecting raw material with lower dimension	0.10	0.00	0.1	1.0	1.0

3.5 Best Available Technologies for a Modern Cement Plant

Figure 3 (refer to Section 2.1) shows that India currently has the best available technologies. Applying all the best available technologies, the following excerpt[13] summarises what a modern energy-efficient cement plant would consist of.

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

Mines
For medium and soft materials, a surface miner with single-stage impact crusher and wobblers can be chosen, whereas for hard materials, conventional mining with two-stage crushing can be selected. Advanced mining with mine-plan software would result in reduced raw-material additives, over-burden handling, and enhanced mine life. Overland conveyors to transport crushed limestone will be beneficial for long-distance transport between mines and plants. Other mine management measures are the installation of mobile crushers for productivity improvement, and radio controlled mine machinery monitoring system for better control and optimisation. Crusher discharge: a cross belt analyser can be installed to ensure the quality and to enhance the mine's life. Stacker and reclaimer with higher blending ratio (of 10:1) can be adopted by design.

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

For limestone with low moisture content (less than 3%), roller press with separator in finished mode can be installed with the following:
- *High-efficiency separators and cyclones.*
- *Automatic sampler and cross-belt analyser in the mill feeding for better quality control.*
- *Adaptive predictive control for mill operation.*

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

[13] Cement Sustainability Initiative, World Business Council for Sustainable Development. Existing and Potential Technologies for Carbon Emissions Reductions in the Indian Cement Industry. 2013. Available from https://openknowledge.worldbank.org/server/api/core/bitstreams/19d9e6e9-77be-56f5-af3a-a0875f47515e/content. Accessed 27 April 2023.

Pyro-processing

Preheater

- *A six-stage or seven-stage preheater is used wherever the heat from preheater and cooler is sufficient to dry fuel and raw material.*
- *Cyclones with high-efficiency and low-pressure drop.*
- *Low NOx calciner with adequate residence time for increased alternative fuel and raw materials (AFR) use in calciner.*
- *HT VFD for preheater fans.*

Kiln

- *Multi-channel burner for improved thermal efficiency, flexibility of firing AFR, better flame control and low NOx emissions.*
- *High strength insulation bricks in kiln inlet and calcining zone.*
- *Kilns operating with high peripheral speed (up to 6–7 RPM).*
- *VFD control for shell cooling fans.*

Coolers

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

Control system

- *Adaptive predictive control system.*
- *Online NOx control.*
- *Online flame control.*
- *Online freelime control.*
- *Flow measurement with advanced techniques.*

Alternative Fuel and Raw materials

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

Coal mill

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

Cement mill

Preferred options for cement grinding could include:

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

Packing plant

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

Minimal Waste Heat Concept

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

Dust Control Equipment

The installation of pulse-jet baghouses with membrane bags for all process applications, and pulse-jet bag filters with non-membrane bags for non-process applications. For clinker coolers, either electrostatic precipitator or bag filters with a waste heat recovery system can be installed." (WBCSD, 2013).

4. UNIDO IEE CASE STUDIES

From a South African perspective, a number of case studies are presented here that demonstrate actual achievements in energy savings despite the challenges faced in the South African electricity supply industry. Examples of successful energy-saving initiatives that have been implemented at cement plants through the UNIDO IEE Project are presented in this section.

The exposition offers a valuable opportunity for industrial companies operating within the cement sub-sector to glean insights from the fruitful outcomes of implemented projects and best practices, enabling them to incorporate such learnings into their own operations.

4.1 Case Study 1 – Lime Manufacturing Plant (EnMS)

The company and its products

Company A is a large producer of burnt lime and dolomite and operates three preheater kilns, each with an approximate monthly yield of 18 000 tons.

As a heavy user of energy in South Africa, the company was hard hit by the rapidly increasing cost of energy with each passing year. Its objective was to minimise operational costs through the reduction of energy consumption (both electrical and thermal). This was achieved through the implementation of an ISO 50001-aligned EnMS.

Financial constraints experienced during the EnMS implementation period forced the company to pivot and focus more effort on identifying and implementing zero-cost opportunities. While the EnMS, through its various features, provided a heightened sense of energy awareness in the company, specific projects that targeted the reduction of thermal energy consumption were implemented to realise savings.

The energy efficiency interventions

The company developed objectives, targets, action plans and energy performance evaluation mechanisms as part of the EnMS. The lime kilns were identified as significant energy users and the projects implemented focused specifically on improving operational control within the kilns' combustion systems.

No cost projects (R10 000)

Improvement in Coal Preparation Techniques (Thermal Energy Savings)

- The coal type used exhibited a high degree of variability in moisture content, calorific value, ash content, and volatiles which made it challenging to achieve consistent combustion. 'Slew stacking' was implemented by the company during the EnMS implementation period, which entailed arranging the coal in uniform layers throughout the entirety of the stockpile bed. This not only reduced variability in the coal that was being reclaimed, but also enhanced the drying of the coal stockpile.

Adjustment of Critical Operating Parameters (Thermal Energy Savings)

- Critical operating parameters were brought within closer limits to achieve consistent and stable operation of the kilns, with the opportunity for further optimisation in the future.

Reduction of False Air (Thermal Energy Savings)

- The presence of air leaks or 'false air' can lead to increased thermal energy consumption as cold air entering the system needs to be heated up to the process temperature, thereby wasting energy. Common potential ingress points include system inlets, outlets, seals, inspection doors, fan casings etc.
- The company set about conducting routine inspections and maintenance to identify false air points by measuring the difference in oxygen content between two different points. The identified leaks were repaired during maintenance shutdowns, with monthly monitoring by the process engineer.

The results

As a result of the energy management programme and the kiln energy performance improvement projects, the lime manufacturing plant has seen the following incremental improvements during the 9-month review period (relative to a 2018 baseline):

- Thermal energy saving of 0.8% of the total thermal energy consumption.
- Reduction in overall energy operating costs amounting to savings of R844 000 per year.
- GHG emission reduction of 2 510 tons equivalent.

Critical success factors

- Understanding the different energy sources and their significant energy users.
- Utilising data effectively to establish energy consumption baselines at a significant energy user (SEU) level.
- Adopting an SEU-targeted approach when identifying potential energy savings projects.
- Developing energy performance indicators to practically demonstrate the energy performance improvement achievements to the leadership team.

4.2 Case Study 2 – Cement Manufacturing Plant (EnMS)

The company and its products

Company B is a large, integrated cement manufacturing plant, with an annual production output of approximately 700 tons per year.

The energy efficiency interventions

The EnMS was implemented between October 2016 and October 2017. Some of the key objectives and targets emanating from the EnMS planning phase were:

- Reduction of electrical energy consumption by 5% (based on 2016 baseline).
- Reduction of thermal energy consumption by 5% (based on 2016 baseline).
- Substitution of 6% of thermal fuel source (coal) with alternative fuels (based on 2016 baseline).
- Raising awareness on ISO 50001 energy management campaign through training at least 75% of plant personnel.

In 2016, the plant utilised four different sources of energy: coal, diesel, electricity and alternative fuel (in the form of recycled tyres). Coal comprised the largest proportion of annual energy consumed at almost 82%, with electricity, tyres and diesel comprising the other sources as illustrated in Figure 9.

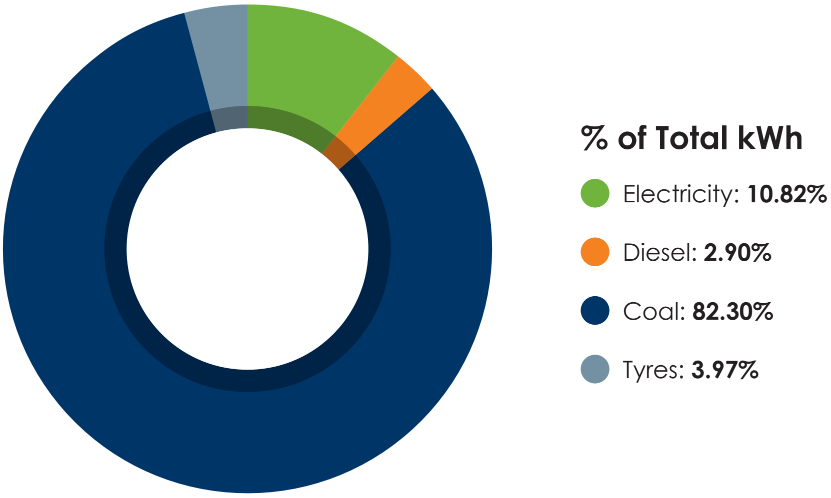

Figure 9: Energy Sources Within Company B

Electrical and thermal energy savings projects were targeted first for implementation, since these presented the highest potential return on investment. Two key projects in the identified SEUs were completed in subsequent months.

Capital Cost Projects (>R50 000)

Installation of Mill Expert Control System (Electrical Energy Savings)

- The MillScan system was installed on the finishing mill in November 2017. Through its vibration-based technologies, this system allows for the optimisation of mill filling level in the respective compartment mills at high frequency, thereby allowing efficient control of the milling circuit.
- Experience from past installations has shown a minimum production increase of 5% if the MillScan signal is used in automated loop control on the fresh feed to the mill. In several cases a production increase of up to 10% has been realised and a subsequent electrical energy saving noted when combined with the MillExCS control software.

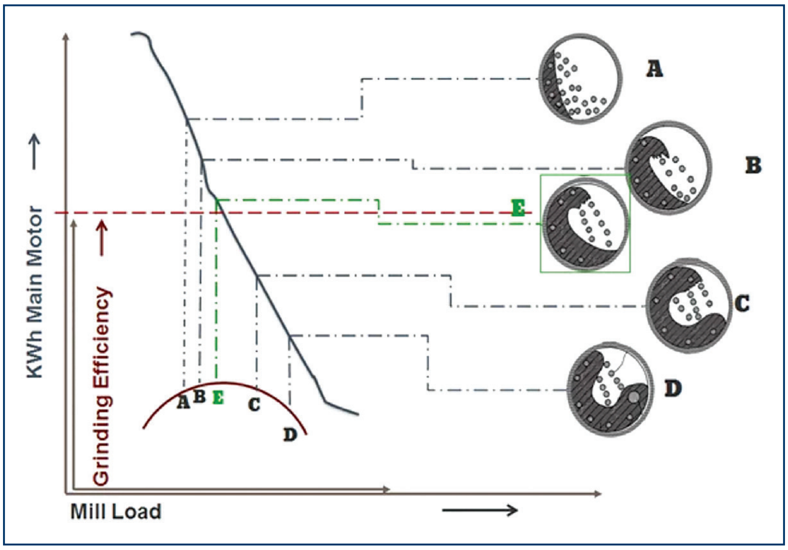

Figure 10: Grinding Efficiency Curve (Mill Load Vs kWh)[14]

[14] https://processiq.com.au/products/milling-flotation-instrumentation/cement-millscan/. Accessed March 2023.

- Optimal milling occurs at the peak of the mill to power curve where steel balls impact the toe of the load (depicted in E [Figure 10]). Many operations, however, run closer to A, resulting in increased energy consumption and liner damage through excessive wear over a shorter period. The MillScan system provides the essential measurements for achieving the optimal power to load ratio thereby maximising throughput and liner longevity while minimising energy consumption.

Reduction of false air in Kiln pre-heater (Thermal Energy Savings)

- 'False air' is one of the common factors that contribute to higher energy consumption in the cement industry. The additional air entry into the pre-heater was found to increase the specific energy consumption of the kiln. The false air ingress points on the kiln walls, ducts and seals, as well as the fan casing were confirmed during the scheduled maintenance periods and were subsequently repaired in January 2018.
- The immediate benefit of reducing the false air requirement was improved fuel efficiency and decreased thermal energy consumption of the kiln.
- Other benefits included more stabilised operating conditions and a resulting increase in productivity.
- Eliminating the additional air also resulted in the fans having to work less hard to maintain the desired airflow and pressure and subsequently less wear on the fan blades, bearings and seals, leading to less downtime and decreased maintenance costs over time.

The results

The electrical energy savings achieved comprised 0.5% of total site electrical energy consumption while the thermal energy savings comprised approximately 0.9% of total site thermal energy consumption.

The company achieved a cumulative electrical energy saving of 4.3% (against the 2016 baseline) over the 10-month period, April 2018–January 2019, for the Mill Expert Control System project with a capital expenditure of approximately R1 000 000.

The energy performance of the kiln was affected in 2017 and 2018 by several factors including an end-of-financial-year stock adjustment for coal consumption, numerous long unplanned stoppages (intermittently over a period of five months) and low limestone feedstocks.

The reduction of false air to the kiln 5 pre-heater project, however, resulted in a cumulative thermal energy saving of 2.1% (against the 2016 baseline) over the 10-month period (April 2018–January 2019). The capital expenditure for the project was approximately R100 000.

Critical success factors

- Awareness training of management personnel prior to embarking on the EnMS implementation journey led to buy-in and commitment at a strategic level.
- Good theoretical understanding of operational processes and the impact of SEU equipment.
- Understanding the need for objectives and targets and action plans (with personnel assigned) to guide the energy savings efforts and assign accountability.

4.3 Case Study 3 – Clinker and Cement Plant (EnMS)

The company and its products

Company C's manufacturing plant was commissioned in the early 1980s to produce just over 600 000 tons of clinker per annum. A second kiln was added in the year 2008 to increase production capacity to just over 1.5 million tons per annum.

The energy efficiency intervention

Some staff members undertook core training at both an end-user and expert level to implement the EnMS. Three energy sources, namely electricity, coal and diesel were quantified, and diesel consumption was found to be negligible. The SEUs for electricity and coal were identified as part of the energy planning phase (shown in Figure 11 and Figure 12) and a list of opportunities documented and prioritised according to capital investment, simple payback period and savings potential.

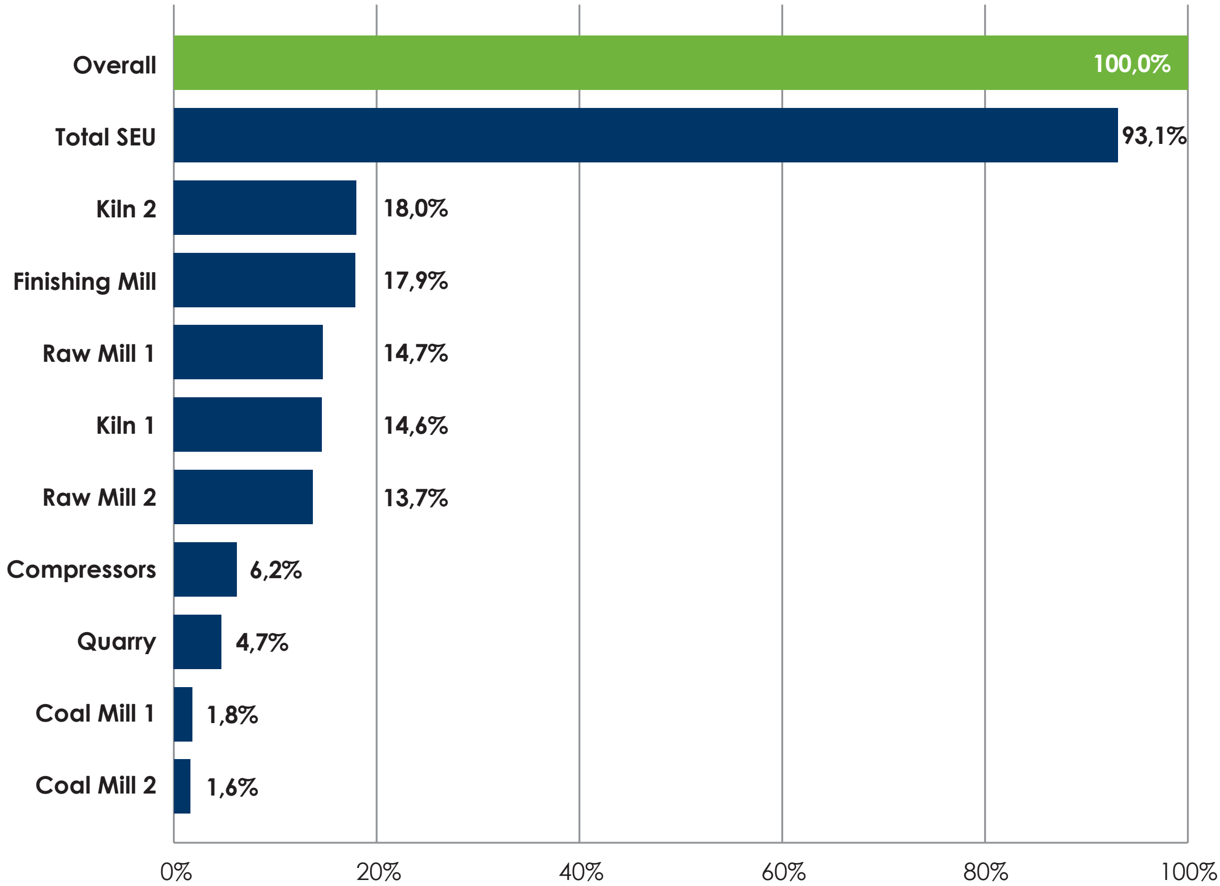

Figure 11: SEU's for Electricity

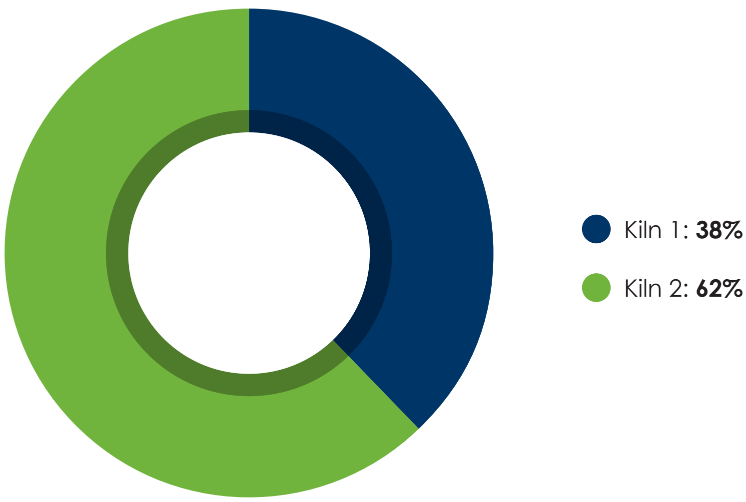

Figure 12: SEU's for Coal

The company was able to realise significant savings in electrical energy and thermal energy (coal), through the implementation of no- and low-cost projects. Several of the identified SEUs were targeted for energy reduction through the grouping of these projects, as described in the following:

No cost projects (< R10 000)

Raw Mills (Electrical Energy Savings)

- Reduction of false air by a target of 20–25%: Identifying points of additional air ingress became a part of mill routine inspections and these were repaired with little cost.
- Operator training on improved outputs: This led to raised awareness of the energy and productivity impacts of operating the raw mill inefficiently.
- Switch off auxiliaries: All auxiliaries on the raw mills were programmed to switch off after 40 minutes with an alarm function. In addition, the raw mill circuit fan was also slowed down.
- Flow control optimisation: The installed Promecon flow measurement device was optimised to control the fan speed based on flow measurement of gas through the mill. This lowered energy costs and led to reduced erosion of the duct wall.

Coal Mills (Electrical Energy Savings)

- Mill optimisation: Improving coal fineness through rigorous particle size monitoring and analysis and optimising primary airflow led to more efficient combustion.
- Stop auxiliaries: All auxiliaries on the coal mills were programmed to switch off after 40 minutes with an alarm function.

Kilns (Electrical and Thermal Energy Savings)

- Reduction of false air by 20%: All holes and leaking doors in the kilns were identified and repaired as part of routine inspections.
- Consideration of energy efficiency in design and procurement phase.

Finishing Mills (Electrical Energy Savings)

- Optimisation of mill grinding media.
- Stop auxiliaries: All auxiliaries on the finishing mills were programmed to switch off after 40 minutes with an alarm function.

Low-cost projects (< R50 000)

Kilns (Electrical and Thermal Energy Savings)

- Reduction of false air: Leak diagnostics in the kiln became a part of routine maintenance and the identified leaks were repaired shortly after.

Capital cost projects

Kilns (Electrical and Thermal Energy Savings)

- Equipment modifications to cyclone: The more capital-intensive interventions involved the installation of a meal flap and dip tube on the cyclone. The meal flap acts as a valve that adjusts the airflow within the cyclone, allowing improved temperature control and oxygen levels within the kiln. Similarly, the installation of a dip tube on the cyclone improved its efficiency by creating a vortex effect and separating the particles more effectively. The cyclone was then able to

capture and remove more solids from the gas stream and reduce the energy required to maintain combustion. Both these modifications to the cyclone resulted in a more efficient combustion process and reduction in energy consumption.
- Replacement of inlet seals: The inlet seals on both kilns were replaced leading to prevention of air leakage and improved energy efficiency of the kilns.
- Operator training: Specific training on the kiln operation (including the energy-related aspects) was conducted. This was very useful in ensuring that all operators understood the energy consumption patterns and effects of the installed kilns.

The most notable opportunity as quoted by the company was the 'stop or switch off auxiliaries' project that was implemented across almost all SEUs. The analysis of historic data on operational parameters revealed that approximately 2.5% of the plant's electrical energy consumed was being wasted by continuing to run auxiliary equipment when main processing units had been switched off. The programmable logic controllers were then modified to include a timer that was set to stop all auxiliaries after a period of 40 minutes, when main equipment was not in operation. The operators were still allowed to intervene in re-setting or stopping the timer if it posed a risk to normal operation. The total cost of implementation was R50 000 with a payback period of less than one month.

The company achieved a cumulative electrical energy saving of 4.2% and a 1.5% cumulative thermal energy saving over a 12-month period.

Critical success factors

- General energy awareness raising of all company personnel and EnMS-specific training for members of the energy team.
- Initially adopting a no- and low-cost project implementation approach and using the initial savings to fund and motivate for the capital-intensive projects. This increased management's confidence in the benefits of an EnMS.
- Using energy performance indicators to track deviations so that mitigation plans could be put in place.
- Involving personnel in the day-to-day operation and improvement of the EnMS led to them becoming more passionate about finding other ways to save energy.

4.4 Case Study 4 – Cement Products Manufacturing Plant (EnMS)

The company and its products

Company D has an annual production capacity of 640 000 tonnes and currently manufactures cement and other cementitious products.

The energy-efficiency intervention

Although an EnMS was previously implemented, it could not be sustained due to the high staff turnover from company restructuring efforts. With renewed vigour in 2019, the appointed energy team embarked on setting key objectives and data-based targets that would lead to the development of energy savings action plans.

Some of the key objectives and targets that were included in the energy policy included:
- Reducing the energy consumption by 5% by 2025 (based on the 2019 baseline).
- Consideration and use of alternative energy sources or energy-efficient products to manufacture cement.
- Annual review and update of the energy policy to commit, optimise and maintain the EnMS.
- Ensuring continual improvement in the plant's energy performance.

Several potential opportunities were identified as part of the energy review of each of the identified significant energy users. These were vetted for techno-economic feasibility and prioritised according to savings potential, investment required, simple payback period and ease of implementation.

Two projects (details follow) were selected for implementation, and these were envisaged to lead to electrical energy savings in the areas of lighting and compressed air.

Low-cost projects (< R50 000)

Lighting Assessment

- A lighting assessment by an independent third party revealed that a good energy savings potential was possible through the retrofitting of energy-efficient LED lighting. A significant potential reduction in maintenance costs and the CO_2 reduction potential (of over 2 000 tonnes) was also highlighted.

Compressed Air Leak Survey

- A detailed compressed air system leak survey was carried out by a compressed air specialist and revealed 237 leaks in the plant. The leaks were tagged, photographed and quantified and were found to equate to an approximate leak rate of ±14.67m³/min.
- This represented approximately 3.8% of total site electrical energy consumption for 2019 and about 4.1% of site total cost of electrical energy. The plant's maintenance personnel went about repairing the leaks and ensured that leak identification was scheduled into the routine maintenance in the future.

The lighting assessment and compressed air survey were used as diagnostic assessments to drill down into the opportunities in these SEUs. The implementation of all recommendations is ongoing.

Capital cost projects

- Installation of VSD on elevator of packaging plant (electrical energy saving). The amps drawn were significantly reduced compared to before the installation. The savings were yet to be verified.
- Disconnection of dedusting fan from old part of plant – compressed air loop (electrical energy saving).

The results

The savings from the implemented capital cost projects were estimated to be in the region of 0.1% of total site electrical energy consumption (based on 2019 baseline).

The company went on to experience significant difficulties in obtaining the relevant data and keeping the EnMS updated, due to several impacting circumstances of the COVID-19 pandemic on the plant and people. Efforts are in place to ensure that the system is updated and maintained.

4.5 Case Study 5 – Clinker and Cement Plant (Compressed Air)

The company and its products

Company E is a cement blending plant that converts clinker into fine cement bulk and bagged products.

The energy-efficiency intervention

Being a significant consumer of electrical energy, the company had already identified the compressors as a significant energy user. With rising energy costs, the company decided to undertake a targeted compressed air systems optimisation assessment which involved establishing energy consumption baselines and performance indicators as well as identifying savings and optimisation opportunities for the reduction of electrical energy. All energy-saving opportunities identified were ranked in order of priority. The company embarked on a drive to implement the opportunities that presented the biggest potential for savings and reducing the carbon footprint.

All projects to be implemented were grouped and the collective cost to implement the three projects following was approximately R1 200 000.

Capital cost projects

- Installation of compressed air blower unit.
- Decoupling the link between the high-pressure and low-pressure systems to improve reliability of compressed air supply.
- Repairing the air leaks that were identified and tagged during the detailed leak survey.

The results

The company managed to achieve an electrical energy saving of almost 2% of total site consumption over an 18-month period.

Critical success factors

- Prioritising identified opportunities in terms of energy savings potential and assigning these to personnel who are held accountable.
- Using a technical specialist who was able to conduct a targeted compressed air systems assessment (including measurement, monitoring and a detailed leak survey).

4.6 Summary of Case Studies

To summarise, the reviewed case studies have showcased the feasibility of identifying, implementing, and attaining energy conservation and that savings are indeed possible largely through no- and low-cost projects in this hard-to-abate sector. The critical success factors that were shared were also instrumental in achieving these savings. A summary of the energy savings achieved are presented in Table 5.

Table 5: Summary of Case Study Energy Savings

Summary of Case Study Energy Savings					
Intervention	**Case A**	**Case B**	**Case C**	**Case D**	**Case E**
Overall energy savings	0.8% (thermal)	0.5% (electrical) 0.9% (thermal)	4.2% (electrical) 1.5% (thermal)	0.1% (electrical)	2% (electrical)

Overall energy savings vary from 0.1% to 4.2% of annual energy consumption (electrical and thermal). No-cost and low-cost projects have resulted in significant savings for some companies and provided the initial momentum to move on to more capital-intensive projects (with possibly higher potential for energy reduction).

While some companies focused on targeted assessments like compressed air, most tended to take a more generic and broad-brush approach with the implementation of an EnMS. In general, companies that have an EnMS are more amenable to investing capital on energy performance improvement projects and are also more willing to implement production-related projects.

5. FUTURE DEVELOPMENTS

Cement is an energy-intensive industry, but currently, electricity accounts for circa 12% within the energy mix, while the rest is various fuels. Total electricity consumption in a dry process is split into equal parts between raw material preparation and clinker production (25% each), then 43% for cement grinding and the remaining for raw material extraction, fuel grinding and for packing and loading. Both the relative share in the energy mix and the usages are expected to change in the near future.

According to the Cembureau trends[15], improvement efforts and future developments include the following:

- Motor efficiency improvements.
- Operating motors with speed drives rather than traditional control methods.
- Replacing ball mills with highly efficient vertical roller mills or high-pressure grinding rolls.
- High-efficiency separators improve product quality but also reduce electrical consumption.
- Installation of modern grate cooler techniques.
- Stricter limits for emissions will increase demand for electrical energy.
- Alternative fuels and resources will become more widespread as an energy reduction technology.
- Carbon capture and storage will become more prevalent.
- Flexible grinding approach could be used for raw meal production and cement manufacturing as power-intensive processes to allow the use of renewable power.
- Use of air separation units to capture CO_2 from clinker production phase and use it to make a byproduct like baking soda.
- Stockpiling raw meal to optimise clinker production schedules.
- Cement producers are investing in wind farms or solar plants to ensure the supply in case of grid instability.
- Using plasma generators in a pre-heater, pre-calciner kiln is at present the main technology path.
- Microwave heating.
- Resistive electrical flow heating.
- Induction heating.
- Heat-recovery turbines.
- Alternative binding materials to Portland Cement clinker can offer opportunities for carbon emissions reductions (e.g. belite cements).
- Cement sintering technique by means of the fluidised bed cement kiln system.

[15] Cembureau. Powering the Cement Industry. Retrieved from: https://cembureau.eu/media/ckkpgrg1/cembureau-view-cement-sector-electricity-use-in-the-european-cement-industry.pdf

6. CONCLUDING SUMMARY

The quest for energy efficiency is of paramount importance in the cement sub-sector in South Africa, especially given its substantial energy consumption and significant carbon emissions. The implementation of energy-efficient measures is thus essential to curtail energy costs, enhance industrial competitiveness, and reduce the industry's environmental footprint.

Recent data reveal that the cement sector accounts for a notable 3% of South Africa's overall energy consumption, with energy costs posing a considerable burden on its operating expenses. Consequently, measures aimed at improving energy efficiency have the potential to generate substantial cost savings, apart from boosting environmental performance.

Advanced technology and equipment offer a key avenue for enhancing energy efficiency in the cement sub-sector. Upgrading kiln systems, employing efficient motors, and implementing energy management systems can substantially mitigate energy usage. Additionally, optimising processes such as raw material blending, clinker production and cement grinding can enhance energy efficiency. The use of alternative fuels, such as biomass and waste materials, represents another effective strategy for promoting energy efficiency. Such fuels can replace conventional fossil fuels, resulting in cost savings and reduced carbon emissions.

Promoting behavioural change and engaging employees in the pursuit of energy efficiency also play a pivotal role in saving energy. Training staff on energy-efficient practices and incentivising energy-saving behaviour are practical methods that can produce significant enhancements in energy performance.

In conclusion, the significance of energy efficiency in the cement sub-sector of South Africa cannot be overstated. By implementing energy-efficient measures, the industry can reduce costs, enhance competitiveness, and contribute to a sustainable future for the country.

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