CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Cement production is widely regarded as one of the most energy-intensive industrial activities worldwide, largely because of the significant thermal and electrical energy required at each stage of the manufacturing process. From raw material preparation to clinker production and final cement grinding, energy consumption remains a dominant factor influencing production efficiency and cost. The clinkerization stage, in particular, demands extremely high temperatures and accounts for the largest share of energy use, making the cement industry a major consumer of fossil fuels and a significant contributor to carbon dioxide (CO_2) emissions (Benhelal *et al*., 2021; IEA, 2023).

In recent years, the cost of cement has risen steadily, both globally and within Nigeria. This increase has been driven by a combination of factors, including rising fuel prices, higher electricity tariffs, unstable power supply, and inefficiencies in energy utilization within cement plants. In Nigeria, where cement plays a critical role in infrastructure development and housing, high production costs have become a major concern for manufacturers, policymakers, and consumers. Energy costs alone often account for a substantial portion of the total cost of cement production, meaning that inefficient energy use directly affects the final price per bag of cement (Adejumo *et al*., 2019; Ojolo *et al*., 2020).

The Nigerian cement industry relies heavily on fossil fuels such as coal and natural gas for thermal energy, as well as grid electricity and captive power generation for electrical operations. Frequent power outages and dependence on self-generated electricity further increase operational costs and energy losses. As a result, effective energy management has become increasingly important for sustaining productivity, reducing operational expenses, and maintaining competitiveness within the industry (Akkaya and Demir, 2017).

Concerns over the rising cost of cement have prompted closer examination of production practices, with energy utilization emerging as a key area requiring attention. This study therefore focuses on an energy audit of a cement processing plant located in Obu, Okpella, Edo State, using BUA Cement Plant as a case study. The study seeks to systematically investigate the sources of energy used in the plant, the major energy-consuming equipment, the amount of energy consumed per tonne of cement produced, and the operational factors responsible for high energy-related production costs.

Energy consumption in cement manufacturing is closely linked to equipment efficiency, process control, and maintenance practices. Poorly maintained equipment, outdated technologies, excessive heat losses, and inefficient grinding operations often lead to unnecessary energy wastage. Beyond increasing production costs, such inefficiencies also contribute to elevated greenhouse gas emissions and other environmental impacts. Addressing these challenges requires a structured and data-driven approach that not only reduces energy losses but also improves productivity, enhances environmental performance, and supports sustainable industrial growth (Aghbashlo *et al*., 2019; Ghosh and Ghosh, 2020).

Energy auditing provides a practical and systematic framework for achieving these objectives. By evaluating how energy is consumed across different production units, an energy audit supports informed decision-making in areas such as energy cost reduction, preventive maintenance, and quality control. It also enables plant management to monitor variations in energy cost, availability, and reliability of supply, determine an appropriate energy mix, and identify suitable energy conservation measures and retrofit options for improved efficiency (ISO, 2018; Schorcht *et al.,* 2017).

At the postgraduate research level, energy auditing goes beyond routine assessments to include performance benchmarking against best available techniques, evaluation of energy performance indicators, and integration of sustainability considerations. This study adopts such an approach to provide practical and evidence-based recommendations aimed at improving energy efficiency, reducing energy-related environmental emissions, boosting productivity, and ultimately lowering the cost of cement production at BUA Cement Plant, Obu, Okpella, Edo State.

1.2 Problem Statement

The high cost of energy significantly impacts the production cost of cement, contributing to increased prices for consumers and affecting the competitiveness of cement manufacturers. Inefficient use of electrical and thermal energy in cement production, including energy losses and suboptimal operational practices, exacerbates this challenge. Despite the critical role of energy in the overall production process, many plants, including BUA Cement Plant, Obu-Okpella, lack a comprehensive assessment of energy-consuming equipment, operational systems, and consumption patterns. This gap hinders the identification of inefficiencies and opportunities for optimization, resulting in elevated operational costs, reduced productivity, and limited scope for sustainable energy management. Therefore, there is a pressing need to evaluate the plant's energy performance, quantify energy use relative to production output, identify areas of energy loss, and develop evidence-based strategies to enhance energy efficiency, reduce costs, and improve operational performance. To achieve these, below are some of the questions asked.

i. What are the installed capacities and operational specifications of the plant's energy-consuming equipment?
ii. How are electrical and thermal energies utilized within the plant's operational systems?
iii. What are the energy consumption patterns across the major production processes?
iv. How does energy consumption correlate with production output, and what is the specific energy consumption (SEC) for benchmarking purposes?
v. Which processes exhibit the greatest energy inefficiencies and losses, and where is the potential for energy savings highest?
vi. What evidence-based strategies can be implemented to enhance energy efficiency, reduce operational costs, and improve overall productivity?

1.3 Aim

The study aims to conduct an energy audit of the BUA Cement Plant, Obu-Okpella.

1.4 Objectives of the Study

i. Assess the plant's energy-consuming equipment, including installed capacities and operational specifications.
ii. Evaluate the operational systems to determine how and where electrical and thermal energy are utilized.
iii. Quantify energy consumption patterns across all major production processes.
iv. Relate energy use to production output by calculating specific energy consumption (SEC) for benchmarking purposes.
v. Identify inefficiencies, energy losses, and processes with the greatest potential for energy savings.
vi. Develop practical, evidence-based recommendations to optimize energy efficiency, reduce costs, and enhance overall productivity.

1.5 Significance of the Study

This study is important because it addresses one of the major challenges in cement manufacturing: high energy consumption. By carrying out a detailed energy audit of BUA Cement Plant, Obu-Okpella, the research sheds light on how energy is used across the plant and highlights areas where improvements can be made. Understanding these energy patterns will help the plant optimize both thermal and electrical energy use, reduce waste, and improve overall efficiency. In practical terms, this can lower production costs, making the cement more affordable and helping the plant remain competitive in the Nigerian market.

Beyond cost savings, the study also supports environmental sustainability, reducing unnecessary energy, lowering greenhouse gas emissions, contributing to cleaner and greener industrial practices. Additionally, the research provides useful insights for decision-making, such as guiding preventive maintenance, upgrading equipment, and improving operational processes. By establishing benchmarks for energy use through specific energy consumption (SEC), the study allows the plant to monitor performance over time and measure improvements against industry standards. Overall, the findings not only benefit BUA Cement Plant but can also serve as a reference for other cement manufacturers and researchers interested in energy efficiency and sustainable production.

1.6 Scope of the Study

This study focuses on how energy is consumed at BUA Cement Plant, Obu-Okpella, looking closely at both thermal and electrical energy throughout the production process. It covers all major stages, from preparing raw materials and producing clinker to grinding and packaging cement. The research examines the plant’s key energy-consuming equipment, their capacities, and how they operate, while also analyzing energy patterns to determine the specific energy used per tonne of cement produced.

The study also identifies which processes are using energy inefficiently and where the greatest opportunities for savings exist. Based on these insights, practical recommendations are made to optimize energy use, reduce costs, and improve productivity. While the research focuses on BUA Cement Plant, the lessons learned could be useful for other cement manufacturing facilities facing similar challenges. In essence, the study provides a clear picture of how energy flows through the plant and offers actionable strategies for making production more efficient, cost-effective, and sustainable.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview of Cement Manufacturing

Cement manufacturing is a complex industrial process that involves the transformation of naturally occurring raw materials into a finely ground hydraulic binder used extensively in construction and civil engineering works. Cement serves as a fundamental component in concrete, mortar, plaster, and other composite materials, providing strength, durability, and structural integrity to buildings, roads, bridges, dams, and other infrastructure projects. Owing to its strategic importance, cement production is often regarded as a key indicator of industrial and economic development in both developed and developing economies. (Portland cement association, 2011).

From a chemical perspective, cement is produced through controlled thermal and mechanical processes that enable a series of physical and chemical reactions. When mixed with water, cement undergoes hydration reactions that result in the formation of calcium silicate hydrate (C–S–H) gel, which is primarily responsible for strength development. The performance characteristics of cement such as setting time, compressive strength, durability, and resistance to environmental degradation are largely determined by its mineralogical composition and fineness (Lea and Mason, 2020).

The cement manufacturing industry is recognized globally as one of the most energy-intensive industrial sectors. Large quantities of thermal and electrical energy are required to extract, crush, grind, heat, and process raw materials at extremely high temperatures. Energy consumption in cement production typically accounts for 30–40% of the total manufacturing cost, making energy efficiency a critical operational and economic concern (Worrell *et al.,* 2018). Consequently, effective energy management practices, including systematic energy auditing, are essential for sustaining competitiveness and reducing production costs.

Cement production is generally classified into wet, semi-wet, semi-dry, and dry processes, based on the method of raw material preparation and moisture content. Among these, the dry process is the most widely adopted in modern cement plants due to its superior energy efficiency and lower fuel consumption. Advances in dry-process technology, such as multi-stage cyclone preheaters, precalciners, and efficient clinker coolers, have significantly reduced specific energy consumption and environmental impacts compared to older wet-process plants (Schneide *et al.*, 2011).

In a typical cement manufacturing operation, limestone, clay, shale, and iron-bearing materials are quarried, crushed, and proportioned to achieve the desired chemical composition. These materials are then finely ground and homogenized to produce raw meal, which is subsequently subjected to high-temperature processing in a rotary kiln system to form clinker as indicated in figure 2.1. The clinker is cooled, mixed with gypsum and other additives, and ground to produce finished cement. Each of these stages contributes differently to overall energy consumption, with pyro-processing and grinding operations accounting for the highest energy demand (Prasunjit Sengupta, 2019).

Beyond its high energy requirements, cement manufacturing is also associated with significant environmental challenges, including greenhouse gas emissions, particulate matter generation, and high resource utilization. Carbon dioxide emissions arise both from fuel combustion and from the calcination of limestone during clinker formation. As a result, improving energy efficiency through process optimization and energy auditing not only reduces operational costs but also contributes to environmental sustainability and regulatory compliance (Madlool *et al.*, 2018).

In developing economies such as Nigeria, cement manufacturing plays a vital role in supporting infrastructure development and economic growth. Large-scale plants such as BUA Cement employ modern production technologies and captive power systems to meet growing domestic demand. However, fluctuations in energy supply, fuel costs, and operational inefficiencies underscore the need for periodic energy audits to evaluate energy performance, identify losses, and recommend practical improvement measures. This study therefore situates cement manufacturing as both an energy-critical and economically strategic industrial activity, providing a strong foundation for examining energy audit practices within the BUA Cement Plant.(Sunday; 2023)

2.2 Cement Production Processes and Techniques

Cement production processes and techniques comprise a structured sequence of mechanical, thermal, and physicochemical operations through which raw materials are transformed into finished cement products that meet prescribed quality and performance standards as shown in figure 2.1. Modern cement manufacturing is increasingly driven by the need to improve energy efficiency, reduce greenhouse gas emissions, and comply with stringent environmental regulations, while maintaining high productivity and product consistency. Recent studies emphasize that the overall efficiency of cement manufacturing systems is largely dependent on process integration, automation, and the adoption of energy-efficient technologies across the production chain (Schneider, *et al*, 2019).

The cement manufacturing process is conventionally divided into three principal stages: raw material preparation, clinker production, and cement grinding. Each stage is characterized by distinct operational requirements, energy consumption patterns, and efficiency challenges. A detailed understanding of these stages is essential for conducting comprehensive energy audits, as it enables the identification of high-energy-demand units, process inefficiencies, and potential areas for energy conservation (Hasanbeigi, *et al* 2017).

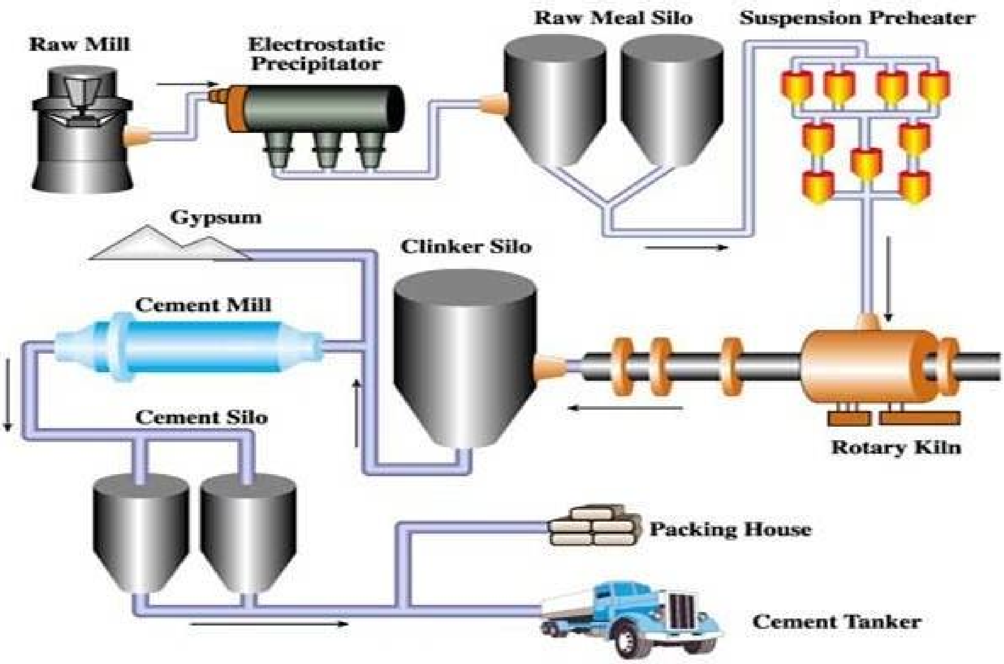

Figure. 2.1**.** Cement production processes (www.flsmidth.com)

2.2.1 Extraction of Raw Materials and Calcination

The extraction of raw materials marks the initial stage of cement manufacturing and involves quarrying limestone, clay, shale, and iron-rich materials from natural deposits Limestone, which supplies calcium carbonate, typically constitutes the largest proportion of the raw mix as represented in figure 2.2a and 2.2b. Variations in mineral composition, moisture content, and particle size of quarried materials significantly influence downstream processing efficiency and energy requirements. Modern quarry management practices increasingly emphasize selective mining and material characterization to enhance process efficiency and reduce energy wastage (Habert *et al.,* 2020).

Calcination is a critical thermochemical process in which calcium carbonate decomposes into calcium oxide and carbon dioxide at temperatures ranging from 850°C to 900°C. This reaction represents one of the most energy-intensive stages of cement production and is a major source of process-related CO_2 emissions. Recent research highlights the importance of optimized calciner design, alternative fuels, and improved heat transfer mechanisms in enhancing calcination efficiency and reducing the overall thermal energy demand of cement plants (Scrivener, *et al*,2018).

Crushing Process

The crushing process involves the size reduction of quarried raw materials into smaller, manageable particles suitable for grinding and homogenization. Modern cement plants employ a combination of primary and secondary crushers, including jaw crushers, gyratory crushers, and impact crushers, selected based on material properties and production capacity. Efficient crushing operations play a crucial role in minimizing the energy demand of subsequent grinding stages, as finer and more uniform feed material reduces mill power consumption (Jeswiet and Szekeres, 2016).

From an energy audit perspective, crushing systems are evaluated for mechanical efficiency, motor performance, and material handling effectiveness. Studies have shown that improper crusher selection, excessive recirculation, and poor maintenance practices can significantly increase electrical energy consumption. Consequently, energy audits often focus on optimizing crusher settings, improving liner design, and implementing condition-based maintenance strategies to enhance energy efficiency (Bearman, *et al*, 2018).

Figure. 2.2a: Crushing plant (Bua Cement plant, 2025)

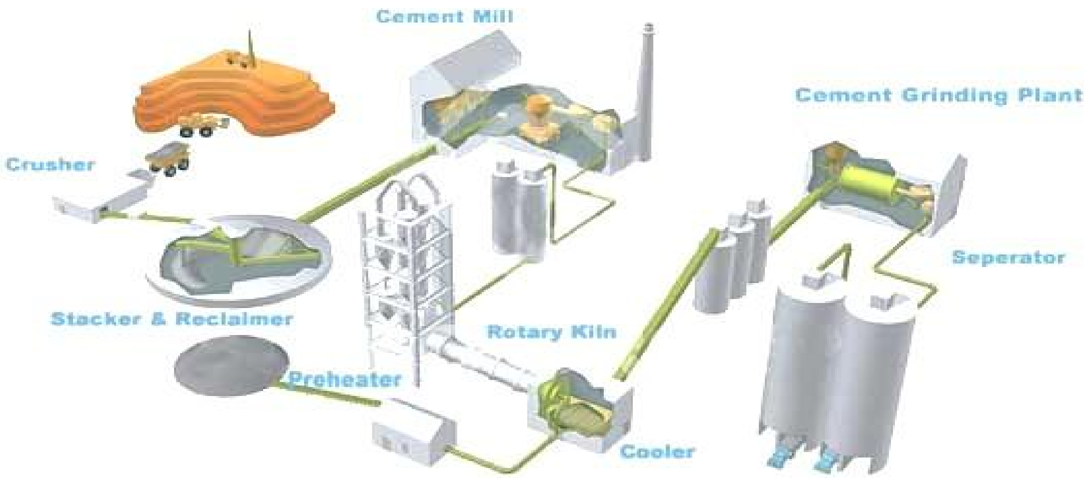

Figure.221b: Cement manufacturing (Source: www.flsmidth.com)

2.2.2 Pyro-Processing (Burning)

Pyro-processing constitutes the central and most energy-intensive stage of cement manufacturing, involving the heating of raw meal to temperatures exceeding 1400°C in rotary kiln systems to form clinker as showed in figure 2.2. This stage typically accounts for the largest share of thermal energy consumption in cement plants. Pyro-processing encompasses preheating, calcination, clinkerization, and controlled cooling, each of which requires precise temperature control and efficient heat utilization (Mikulčić, Klemeš, Vujanović, and Duić, 2016).

Efficient kiln operation depends on stable feed chemistry, optimized fuel combustion, and effective heat recovery. Recent studies emphasize the role of advanced process control systems, real-time monitoring, and alternative fuel integration in improving kiln thermal efficiency and reducing fuel consumption. As a result, pyro-processing is a primary focus area in detailed energy audits aimed at achieving significant energy savings and emission reductions in cement plants (Benhelal *et al.,* 2018).

Figure 2.3 Pyro Process of the cement ;(Bua cement plant. 2025)

2.2.3 Raw Meal Grinding (Raw Mill)

Raw meal grinding involves the drying, pulverization, and blending of raw materials to produce a fine, homogeneous powder suitable for kiln processing. Vertical roller mills and high-efficiency ball mills are commonly employed in modern cement plants due to their improved energy performance and operational flexibility. Raw grinding is an electricity-intensive operation and contributes substantially to the total electrical energy consumption of cement manufacturing facilities (Fujimoto, *et al*, 2020).

The efficiency of raw mills is influenced by several operational factors, including feed moisture content, grinding pressure, classifier efficiency, and ventilation conditions. Recent research indicates that improper mill operation can lead to excessive power consumption and unstable kiln feed quality. Consequently, energy audits frequently assess raw mill performance metrics and control strategies to identify opportunities for reducing electrical energy use and improving process stability (Hajforoush, Haidari, and Ramezanianpour, 2019).

Figure 2.4. Raw mill; (***B***ua Cement plant, 2025***)***

2.2.4 Homogenization

Homogenization is a critical process that ensures uniform chemical composition of the raw meal prior to kiln feeding. Effective homogenization minimizes fluctuations in kiln feed chemistry, thereby enhancing kiln stability, reducing fuel consumption, and improving clinker quality. Modern cement plants employ blending silos equipped with advanced aeration and control systems to achieve high degrees of raw meal uniformity (Gartner and Hirao, 2015).

From an energy management perspective, improved homogenization contributes indirectly to energy efficiency by stabilizing thermal processes and reducing the need for corrective actions during kiln operation. Energy audits often evaluate the design and performance of homogenization systems to determine their effectiveness in supporting efficient and stable production conditions (Zhang, *et al,* 2021).

Figure. 2.5 Homogenization, (Bua Cement plant, 2025)

2.2.5 Preheating and Clinker Production

Preheating systems are designed to recover heat from kiln exhaust gases and transfer it to the incoming raw meal before it enters the calciner and kiln. Multi-stage cyclone preheaters are widely adopted in modern dry-process cement plants due to their high heat recovery efficiency and ability to significantly reduce fuel consumption. Studies indicate that advanced preheating systems can lower specific thermal energy consumption by up to 25–30% compared to conventional kiln configurations (IEA, 2018).

Clinker production occurs at peak temperatures of approximately 1450°C, where complex solid-state and liquid-phase reactions form the principal clinker minerals. The efficiency of clinker formation is highly sensitive to temperature control, residence time, and material flow characteristics. Energy audits of clinker production systems focus on evaluating heat transfer efficiency, fuel utilization, and process stability to identify potential improvements in thermal performance (Rahman, *et al* 2017).

Figure 2.6a Cyclone preheater.(Bua cement plant, 2025)

Figure 2.6b Cement Rotary Kiln.(Bua Cement Plant, 2025)

2.2.6 Cement Grinding Mill

Cement grinding represents the final mechanical stage of cement manufacturing and involves milling clinker with gypsum and supplementary cementitious materials to achieve the required fineness and performance characteristics. This stage is one of the most electricity-intensive processes in cement plants and often accounts for a significant proportion of total electrical energy consumption. Recent studies highlight the growing adoption of energy-efficient grinding technologies, such as vertical roller mills and high-pressure grinding rolls, to reduce power demand (Van den Heede and De Belie, 2016).

Energy audits of cement grinding systems typically focus on mill design, separator efficiency, grinding media characteristics, and process control strategies. Optimization of these parameters has been shown to yield substantial reductions in specific energy consumption while maintaining or improving product quality (Kang, Wang, and Zhang, 2020).

Figure 2.7: Cement grinding mill ;(Bua cement 2025)

2.2.7 Cement Silos

Cement silos are used for the storage and handling of finished cement prior to packaging or bulk dispatch. Proper silo design and operation are essential to prevent material segregation, moisture ingress, and loss of product quality. Modern silos are equipped with automated aeration, level monitoring, and discharge control systems to ensure efficient material flow and minimize operational disruptions (De Weerdt, Benhelal, and Van Tittelboom, 2018).

Although cement silos are not among the highest energy-consuming units, auxiliary systems such as compressed air supply, conveying equipment, and ventilation systems contribute to overall energy use. Energy audits therefore assess silo-related auxiliary energy consumption to identify opportunities for reducing compressed air losses and improving motor efficiency (ISO, 2018).

Figure 2.8: Cement Silos ;(CMQ Engineering)

2.2.8 Packing and Transportation

Packing and transportation constitute the final stage of cement manufacturing and involve the bagging or bulk loading of cement for distribution to end users. Automated packing machines, belt conveyors, and pneumatic transport systems are commonly employed to ensure accuracy, efficiency, and high throughput. Recent studies indicate that improvements in motor efficiency, control systems, and logistics planning can significantly reduce energy consumption and operational costs in this stage (Hossain, Hasan, and Rahman, 2019).

From an energy audit standpoint, packing and transportation systems are evaluated for motor loading, compressed air efficiency, and material handling optimization. Although the energy demand of this stage is relatively lower compared to pyro-processing and grinding, cumulative energy savings can be achieved through systematic efficiency improvements and operational optimization (Zhao, Wang, and Li, 2021).

Figure 2.9 Packaging section (Bua Cement, 2025)

2.3 Rotary Kiln Process and Thermal Efficiency

The rotary kiln system constitutes the central thermal processing unit in cement manufacturing and exerts a dominant influence on the overall energy performance of cement plants. The extremely high temperatures required for clinker formation make the rotary kiln the largest consumer of thermal energy within the cement production chain. Consequently, kiln design characteristics, operating conditions, and heat recovery effectiveness are critical determinants of fuel efficiency and production cost. Contemporary studies emphasize that improvements in kiln thermal efficiency are among the most impactful strategies for reducing energy intensity and carbon emissions in cement manufacturing (Gursel, Masanet, Horvath, and Stadel, 2016).

2.3.1 Description and Operating Principle of the Rotary Kiln

A rotary kiln is a refractory-lined, cylindrical steel vessel installed at a slight inclination and rotated at a controlled speed to facilitate material movement and heat transfer. Raw meal is introduced at the upper end of the kiln and progresses gradually toward the lower discharge end as a result of gravitational force and rotational motion. Thermal energy is supplied through a high-temperature flame generated by fuel combustion at the kiln's lower end, creating a counter-current heat exchange system that enhances thermal efficiency (Boateng and Barr, 2020).

In modern cement plants, rotary kilns are integrated with multi-stage cyclone preheaters and precalciner units that enable partial or complete calcination of raw meal prior to kiln entry. This configuration significantly reduces the thermal load on the kiln, shortens material residence time, and lowers specific fuel consumption. The integration of these systems has been shown to improve operational stability and energy performance in large-scale cement plants (Khurshid, Sadiq, and Ahmed, 2021).

2.3.2 Thermal Energy Consumption in Rotary Kilns

Thermal energy consumption in rotary kilns is governed by a combination of design parameters and operational conditions, including kiln dimensions, raw meal chemistry, fuel properties, excess air levels, and process control efficiency. Recent benchmarking studies indicate that state-of-the-art dry-process rotary kilns typically operate within a thermal energy range of approximately 3.0–3.5 GJ per tonne of clinker, while older or poorly optimized systems may exceed these values considerably (Wang, Chen, and Yang, 2020).

Major sources of thermal losses in rotary kilns include hot exhaust gases, radiation from the kiln shell, and incomplete fuel combustion. Energy audits focus on identifying and quantifying these losses through detailed heat balance analyses. Reductions in thermal energy consumption are commonly achieved through improved insulation, optimized burner operation, and enhanced heat recovery integration (Arias, Molina, and Pérez, 2019).

2.3.3 Heat Transfer Mechanisms and Efficiency Factors

Heat transfer within the rotary kiln occurs through radiative, convective, and conductive mechanisms, with radiation being the dominant mode at high operating temperatures. The effectiveness of heat transfer depends on flame geometry, kiln rotation speed, bed depth, material emissivity, and refractory lining properties. Recent numerical and experimental studies have demonstrated that optimized flame shape and uniform temperature distribution significantly enhance heat utilization efficiency within the kiln (Li, Zhou, and Zhang, 2022).

Advancements in kiln burner technologies, including low-NOx burners and high-momentum burners, have improved flame stability and heat penetration into the material bed. Energy audits often assess burner performance and flame characteristics to ensure efficient heat transfer and minimize energy losses associated with uneven temperature profiles and localized overheating (Sui, Wang, and Liu, 2018).

2.3.4 Clinker Cooling and Heat Recovery Systems

Clinker cooling is a critical downstream operation that strongly influences overall kiln thermal efficiency and clinker quality. Following clinker formation at temperatures approaching 1450°C, rapid cooling is required to stabilize desirable mineral phases and prevent adverse phase transformations. Modern cement plants predominantly employ grate coolers due to their superior heat recovery capability and operational reliability (Bonavetti, Donza, and Rahhal, 2017).

Efficient clinker coolers are designed to recover a significant fraction of the sensible heat from hot clinker and convert it into secondary and tertiary combustion air for the kiln and calciner. Recent investigations report that optimized cooler operation can recover up to 30–40% of the total thermal energy input, thereby substantially reducing primary fuel demand and improving overall plant efficiency (Zhang, Ma, and Xu, 2020).

Figure 2.10: Clinker Cooler.(www.globalccinstitue.com)

2.3.5 Rotary Kiln Performance Evaluation in Energy Audits

In energy auditing practice, the performance of rotary kiln systems is evaluated using key indicators such as specific heat consumption, clinker output stability, exhaust gas temperature profiles, and heat recovery efficiency. Deviations from established benchmarks often indicate the presence of operational inefficiencies, equipment wear, or suboptimal control strategies (Moya, Pardo, and Mercier, 2019).

Comprehensive rotary kiln energy audits typically involve detailed mass and energy balance calculations, infrared thermographic surveys to detect shell heat losses, and assessments of combustion efficiency and air leakage. The findings of such audits provide a technical basis for recommending targeted improvement measures, including refractory upgrades, burner redesign, waste heat recovery optimization, and advanced process control implementation to enhance thermal efficiency and reduce fuel consumption (Kermeli, *et al* 2020).

2.4 Fuel Systems and Firing Techniques

Fuel systems and firing techniques are central to how efficiently a cement kiln operates. Because fuel combustion supplies most of the thermal energy required for clinker formation, the way fuel is selected, prepared, and burned has a direct impact on kiln efficiency, operating costs, and environmental performance. In practice, even small inefficiencies in fuel use can lead to significant increases in energy consumption and emissions. For this reason, fuel systems receive close attention during energy audits of cement plants, particularly in modern operations seeking to balance productivity with sustainability goals (Oberschelp, *et al*, 2019).

2.4.1 Types of Fuels Used in Cement Kilns

Traditionally, cement kilns have depended on fossil fuels such as coal, petroleum coke (petcoke), natural gas, and heavy fuel oil. These fuels are preferred because of their relatively high calorific values and predictable combustion behaviour, which make it easier to maintain stable kiln temperatures. Coal and petcoke, in particular, remain dominant in large-scale cement plants due to their availability and comparatively low cost. However, differences in fuel composition such as ash content, moisture level, and volatile matter—can significantly affect combustion efficiency and, ultimately, clinker quality (Oates, 2017).

In response to rising fuel costs and increasing environmental pressure, many cement plants now incorporate alternative fuels into their energy mix. These alternatives include biomass, municipal solid waste, industrial residues, and agricultural by-products. When properly managed, alternative fuels can partially replace conventional fossil fuels without disrupting kiln operation. Research shows that well-planned fuel substitution strategies can reduce fuel expenditure and carbon emissions while maintaining acceptable clinker quality and kiln stability (Vilkner, *et al*, 2021).

2.4.2 Fuel Preparation and Handling Systems

Before fuel can be used effectively in a cement kiln, it must be prepared and handled in a way that supports stable and complete combustion. Solid fuels such as coal and petcoke typically undergo crushing, drying, and pulverization to achieve suitable particle size and moisture content. If these preparation stages are poorly controlled, the result may be uneven combustion, higher fuel consumption, and fluctuating kiln temperatures, all of which negatively affect energy efficiency (Kourti, *et al*, 2018).

During energy audits, fuel preparation and handling systems are assessed not only for their thermal impact but also for their electrical energy use and operational losses. Auditors commonly identify opportunities to improve mill efficiency, enhance drying performance, and reduce material spillage. Such improvements contribute to more consistent fuel delivery and better overall energy performance of the kiln system (Schorcht *et al*., 2017).

2.4.3 Firing Techniques and Burner Design

Firing techniques describe how fuel and combustion air are introduced into the kiln and mixed to release heat effectively. Modern cement kilns rely on advanced multi-channel burners that allow operators to control flame shape, fuel distribution, and combustion intensity with a high degree of precision. Well-designed burners help produce uniform temperature profiles along the kiln, which improves heat transfer to the material bed and supports stable clinker formation (Sui, *et al*, 2018).

In addition, developments in firing technology such as staged combustion and low-NOx burner systems have made it possible to improve thermal efficiency while limiting harmful emissions. From an energy audit standpoint, burner performance is evaluated in terms of flame stability, air–fuel mixing, and excess air levels. Adjustments in these areas often yield measurable reductions in fuel consumption and emission levels (Li, *et al*, 2020).

2.4.4 Combustion Control and Air Management

Effective combustion control depends on the careful regulation of air supplied to the kiln. Primary, secondary, and tertiary air streams must be balanced to ensure complete fuel combustion and efficient heat utilization. Excess air lowers flame temperature and increases heat losses through exhaust gases, while insufficient air can cause incomplete combustion and higher fuel usage. Achieving the right balance is therefore essential for maintaining kiln efficiency and operational stability (González, *et al*, 2019).

Most modern cement plants employ advanced control systems and real-time monitoring tools to manage combustion conditions. During energy audits, attention is given to the performance of oxygen sensors, air flow controls, and potential air leakage points. Correcting deficiencies in these areas can significantly improve fuel utilization and reduce unnecessary thermal losses (Moya, *et al*, 2021).

2.4.5 Implications of Fuel Systems on Kiln Efficiency and Energy Audits

The combined performance of fuel systems and firing techniques has a direct and measurable influence on kiln thermal efficiency, clinker quality, and emission levels. Poor fuel utilization leads to higher specific heat consumption and increased operating costs, whereas well-optimized systems support stable operation and improved energy performance. For this reason, energy audits place strong emphasis on evaluating fuel selection, preparation processes, combustion efficiency, and air management practices within the kiln system (Aranda *et al*, 2020).

Assessments of fuel systems during energy audits allow cement plants to identify practical opportunities for fuel substitution, combustion optimization, and emission reduction. Beyond immediate energy savings, these improvements also contribute to long-term environmental sustainability and compliance with regulatory requirements, underscoring the strategic importance of fuel systems in modern cement manufacturing operations (Zhao; *et al*, 2022).

2.5 Clinker Composition and Mineralogy

Cement clinker is the fundamental intermediate product in the production of Portland cement. Its chemical composition and mineralogical characteristics critically determine the strength, setting behavior, durability, and hydration properties of the final cement product (Termiz, 2023; Nuhu et al., 2025). Clinker is formed by the high-temperature reaction of selected raw materials primarily limestone ($CaCO_3$), clay (SiO_2, Al_2O_3), bauxite (Al_2O_3), and iron ore (Fe_2O_3) in the rotary kiln at temperatures typically ranging between 1400°C and 1500°C (Król *et al.,* 2022). The formation of clinker involves a series of chemical reactions that produce four principal mineral phases, each with distinct contributions to cement performance:

1. **Tricalcium Silicate (C_3S; $3CaO \cdot SiO_2$)**: Also known as *alite*, C_3S is the most reactive silicate phase and primarily controls early strength development. Its rapid hydration

releases significant heat, making it vital for early-age structural applications (Król et al., 2022; Termiz, 2023).

2. **Dicalcium Silicate (C_2S; $2CaO·SiO_2$)**: Known as *belite*, C_2S hydrates more slowly than alite, contributing mainly to long-term strength and durability. The proportion of C_2S influences the rate of strength gain beyond 28 days (Król *et al.,* 2022).
3. **Tricalcium Aluminate (C_3A; $3CaO·Al_2O_3$)**: C_3A governs the initial setting time and is responsible for the exothermic reaction during early hydration. Excessive C_3A can lead to rapid setting and susceptibility to sulfate attack, thus necessitating the addition of gypsum to regulate its reactivity (Termiz, 2023).
4. **Tetracalcium Aluminoferrite (C_4AF; $4CaO·Al_2O_3·Fe_2O_3$)**: This mineral contributes minimally to strength but plays a role in kiln melting behaviour and clinker coloration. C_4AF reduces the temperature required for clinkerization, promoting efficient kiln operation (Termiz, 2023; Nuhu *et al*., 2025).

The proportion of these minerals in industrial clinker typically varies depending on raw material composition and process control. Studies indicate that C_3S constitutes 56.5–73.9%, C_2S 4.1–24.5%, C_3A 0.8–8.4%, and C_4AF 7.4–13.9% in representative industrial clinkers (CemConRes, 2024). Such variations underscore the importance of precise raw mix design, kiln temperature management, and cooling rate control to ensure optimal cement performance.

Advanced characterization techniques, including quantitative X-ray diffraction (XRD), Rietveld refinement, and scanning electron microscopy (SEM), are employed to analyze the clinker mineralogical phases. These methods provide more accurate phase quantification than traditional Bogue calculations, accounting for polymorph variations and minor phases that influence hydration reactivity and strength (Castanon *et al*., 2012; Benmohamed *et al.,* 2016).

Moreover, the incorporation of minor oxides (e.g., MgO, Na_2O, K_2O) into silicate phases affects polymorphic stability and hydraulic reactivity. For instance, MgO substitution in C_3S stabilizes reactive polymorphs and improves early strength characteristics, highlighting the complex interplay between chemical composition and clinker mineralogy

Table 2.1: Raw Ingredients for Clinker Formation

Raw Material	Major Oxides (%)	Remarks
Limestone	CaO: 50–55	Main source of lime
Clay	SiO_2: 45–55	Source of silica & alumina
Bauxite	Al_2O_3: 30–40	Enhances C_3A content
Iron Ore	Fe_2O_3: 5–10	Promotes C_4AF formation

Source: *Grokipedia. (2026).*

Table 2.2: Typical Clinker Mineral Composition

Mineral Phase	Weight % Range	Function
C_3S	56.5–73.9	Early strength
C_2S	4.1–24.5	Long-term strength
C_3A	0.8–8.4	Setting control
C_4AF	7.4–13.9	Color & kiln efficiency

Source: *Grokipedia. (2026).*

Tables 2.1 and 2.2 show how the raw material composition influences clinker mineralogy. Limestone provides CaO for silicate formation, clay supplies SiO_2 and Al_2O_3, bauxite enhances C_3A, and iron ore promotes C_4AF formation. The resulting clinker consists mainly of C_3S for early strength, C_2S for long-term strength, C_3A for setting control, and C_4AF for color and kiln efficiency. This highlights the direct link between raw material proportions and the functional properties of clinker (Grokipedia, 2026).

2.6 Clinker Production Reactions

Clinker production is the core thermochemical transformation process in cement manufacturing, where raw material oxides are converted into hydraulic mineral phases under controlled high-temperature conditions. This multistage process occurs sequentially in the preheater, calciner, rotary kiln, and clinker cooler, and it fundamentally determines the mineralogical makeup, reactivity, and quality of the resulting clinker (Hasanbeigi and Price, 2015; Król et al., 2022).

Understanding the reactions that take place at each stage is essential for optimizing both product performance and energy efficiency, as well as for minimizing emissions and material waste.

The entire clinker production reaction sequence can be grouped into three major stages: calcination, clinkerization, and rapid cooling**.**

2.6.1 Calcination

Calcination is the initial high-temperature reaction in clinker formation, occurring primarily in the preheater and calciner between 700 °C and 900 °C**.** During this stage, the dominant reaction is the thermal decomposition of calcium carbonate ($CaCO_3$) the principal component of limestone into calcium oxide (CaO) and carbon dioxide (CO_2)**:**

$$CaCO_3 \rightarrow CaO + CO_2\uparrow \tag{2.1}$$

This endothermic reaction consumes a significant portion of the thermal energy input to the cement kiln system and produces reactive lime (CaO) that is indispensable for subsequent mineral formation (Hasanbeigi & Price, 2015). Efficient calcination requires uniform heat distribution and prolonged exposure to temperatures above the decomposition threshold. If calcination is incomplete, unreacted $CaCO_3$ can persist into the kiln, leading to variable clinker quality and elevated free lime, which negatively affects cement hydration and strength development (Worrell et al., 2018).

In practice, modern preheater-calciner systems leverage multi-stage cyclone heat exchange to recover heat from kiln exhaust gases, thereby enhancing thermal efficiency and lowering fuel consumption per unit of clinker produced (Hasanbeigi & Price, 2015).

2.6.2 Clinkerization

Clinkerization refers to the chemical reactions occurring in the rotary kiln between approximately 1250 °C and 1500 °C, where the primary clinker minerals form through solid-state and liquid-phase reactions among CaO, SiO_2, Al_2O_3, and Fe_2O_3. The progression can be conceptualized as follows:

1. **Silicate Phase Formation:** As temperature rises above 1250 °C, CaO reacts with silica to form intermediate compounds, ultimately yielding tricalcium silicate (C_3S) and dicalcium silicate (C_2S) in the presence of a transient liquid phase:

$$2CaO \cdot SiO_2 + 3CaO \cdot SiO_2 \rightarrow C_3S + C_2S \quad (2.2)$$

The formation of C_3S, the most hydraulically reactive silicate phase, is highly dependent on both temperature and the presence of a transient melt. The transient liquid phase enhances diffusion, enabling silicate and aluminate species to reorganize into stable clinker minerals (Król et al., 2022).

2. **Aluminate and Ferrite Phase Formation:** Alumina and iron oxides react with CaO to form tricalcium aluminate (C_3A) and tetracalcium aluminoferrite (C_4AF)**:**

$$3CaO \cdot Al_2O_3 + 4CaO \cdot Al_2O_3 \cdot Fe_2O_3 \rightarrow C_3A + C_4AF \quad (2.3)$$

C_3A forms at relatively lower temperatures within the clinkerization range and strongly influences early setting behavior and sulfate resistance. C_4AF forms by incorporating iron into the aluminate structure, which lowers the liquid phase formation temperature, thus aiding clinker mineral synthesis while affecting clinker color and kiln chemistry (Król et al., 2022; Termiz, 2023).

The kinetic pathways during clinkerization are not purely stoichiometric; mineral phase development is influenced by raw mix chemistry, thermal gradients, residence time, and phase equilibria in the $CaO–SiO_2–Al_2O_3–Fe_2O_3$ system. Deviations in these variables can shift the proportions of C_3S, C_2S, C_3A, and C_4AF, impacting eventual cement performance characteristics (Worrell *et al*., 2018).

The process moves from the left to right.

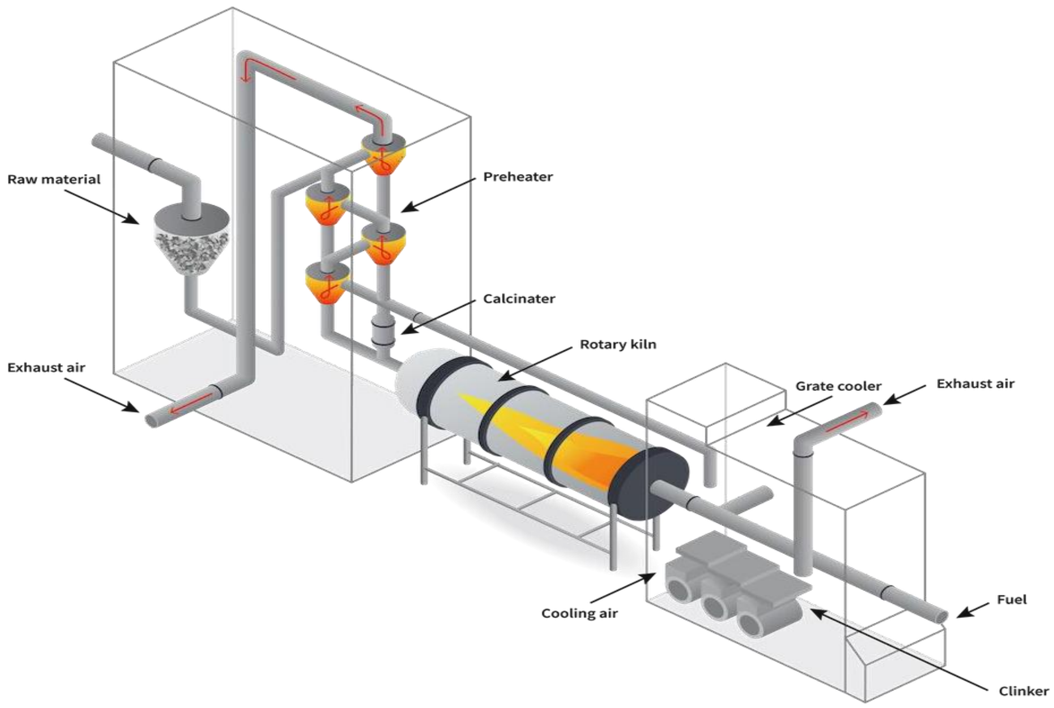

Figure 2.11: Calcination process of clinker (www.scribd.com)

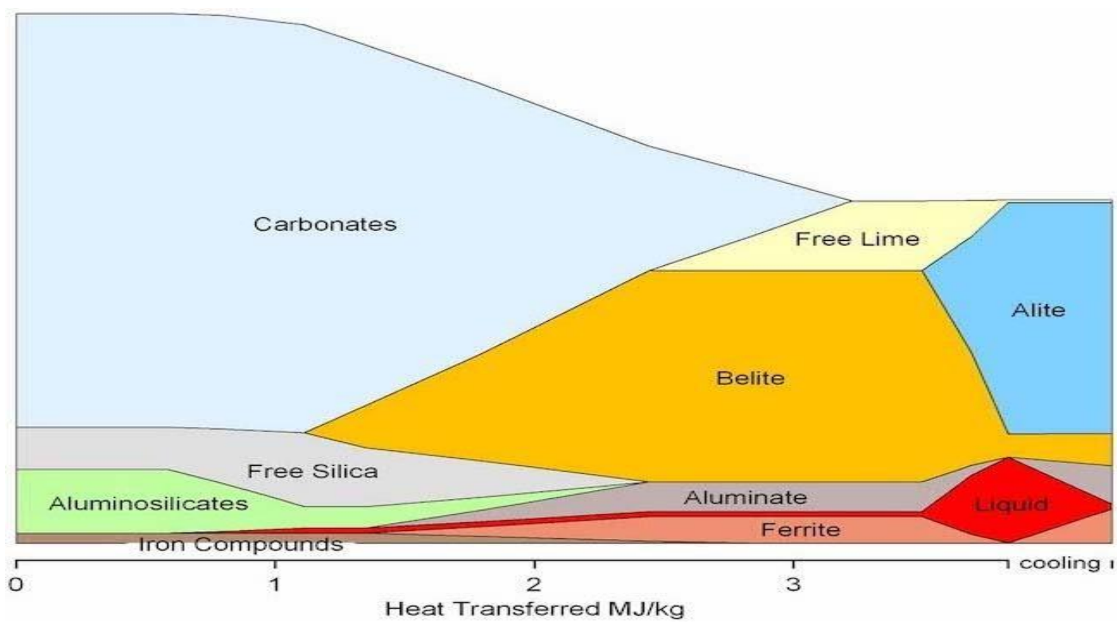

Figure 2.12 Mineral transformation in clinker production; (www.scribd.com)

2.6.3 Rapid Cooling and Phase Stabilization

Once clinker minerals have formed at peak temperatures (usually near 1450 °C), the material must be cooled rapidly to preserve the reactive silicate phases, particularly C_3S. Prolonged exposure to elevated temperatures during slow cooling promotes reverse transformations such as the conversion of reactive C_3S polymorphs into less reactive forms and the formation of excessive free lime, which can detrimentally affect cement hydration and compressive strength (Taylor, 2021).

Modern clinker coolers reduce material temperatures from roughly 1450 °C to below 100 °C within minutes**,** stabilizing the desirable hydraulic phases and minimizing unwanted polymorphic conversions. Efficient clinker cooling also recovers heat for reuse in the preheater and calciner, contributing to improved energy performance of the plant (Hasanbeigi & Price, 2015).

2.6.4 Integrated Reaction Dynamics

The clinker production reactions are inherently interconnected: uniform calcination ensures adequate reactive lime supply, which in turn supports complete silicate and aluminate reactions during clinkerization. Similarly, optimal kiln design and temperature control ensure the right balance between solid and transient liquid phases necessary for mineral formation (Król et al., 2022). Monitoring these reactions through process instrumentation and real-time mineralogical analysis (e.g., on-line XRD) enables plants to maintain product quality and regulatory compliance (CemConRes, 2024).

2.7 Energy Audit Activities and Types

Energy auditing is a systematic, structured, and comprehensive assessment of energy use in industrial facilities. Its purpose is to understand how energy is consumed, where inefficiencies occur, and how consumption can be optimized without compromising production output (Anoune et al., 2023; Capehart, Turner, & Kennedy, 2020). In cement manufacturing, energy auditing is particularly critical because the production of cement is highly energy-intensive**,** with substantial thermal and electrical energy requirements for clinker production, grinding, and auxiliary operations. Proper auditing ensures cost-effective, efficient, and environmentally sustainable operations**.**

An energy audit serves as both **a** diagnostic tool and a strategic planning instrument. Diagnostically, it identifies energy losses, inefficient equipment, heat wastage, and suboptimal process control. Strategically, it provides a foundation for long-term energy management, enabling organizations to set benchmarks, implement targeted improvements, and evaluate the impact of interventions over time (IJEER, 2023; MDPI Energies, 2023).

2.7.1 Energy Audit Activities

The energy audit process is typically multi-staged and methodical, involving a combination of data collection, analysis, and implementation. The following are the key activities:

2.7.1.1 Data Collection and Analysis

The audit process begins with the systematic collection of data, including historical energy bills, fuel consumption records, production logs, equipment inventories, and operating schedules. Advanced facilities may also utilize real-time monitoring systems, such as smart meters, temperature sensors, flow meters, and SCADA systems, to capture detailed energy consumption patterns. Collected data is then analyzed to establish baseline performance, quantify energy flows, and detect anomalies in energy usage (Thakare, 2018).

2.7.1.2 On-Site Inspection and Process Observation

Following data collection, auditors conduct site visits to verify the accuracy of data and observe actual operational practices. In cement plants, this may involve inspecting kilns, raw mills, cement mills, fans, compressors, conveyors, and auxiliary systems. Site inspections provide valuable insights into inefficiencies not captured in recorded data, such as leaks, improper equipment settings, or inconsistent operational schedules (Palli, 2024).

2.7.1.3 Energy Flow and Loss Analysis

Energy analysis involves quantitative evaluation of energy flows through the plant. Techniques include energy balance calculations, thermal and electrical efficiency assessments, and process simulations. The aim is to identify high-energy-consuming subsystems, operational bottlenecks, and energy loss points. This stage is crucial for pinpointing opportunities for efficiency improvements and cost reduction (Hasanbeigi and Price, 2015).

2.7.1.4 Recommendations and Feasibility Assessment

Based on the audit findings, auditors prepare a report detailing prioritized recommendations, including technical, operational, and financial feasibility assessments. Recommendations may range from low-cost operational changes to capital investments in energy-efficient equipment or process optimization (IJERT, 2014).

2.7.1.5 Implementation and Monitoring

Recommended interventions are implemented in collaboration with plant management and technical teams. Continuous monitoring ensures that measures achieve intended energy savings and operational improvements. Monitoring may involve establishing key performance indicators (KPIs) to track energy consumption trends and ensure sustained efficiency gains (Worrell; et al 2018)

2.7.1.6 Strategic Role in Energy Management

Beyond operational improvements, energy audits provide a strategic framework for long-term energy management**.** They establish a baseline for benchmarking, facilitate energy reporting for regulatory compliance, and support the development of Energy Management Systems (EnMS) that promote continuous improvement, performance tracking, and sustainability initiatives (IJERT, 2014).

2.7.2 Classification of Energy Audits

Energy audits are classified according to scope, depth of analysis, and strategic objectives**.** Each classification serves a specific purpose in identifying and implementing energy-saving measures (Muhammad *et al*., 2019; Sharma *et al*., 2021):

2.7.2.1 Preliminary (Walk-Through) Audits

Preliminary audits are rapid, qualitative assessments that identify obvious areas of energy waste. These audits typically involve visual inspections, review of historical energy consumption, and informal discussions with staff. While they do not quantify energy savings precisely, they are highly effective in identifying low-cost or no-cost interventions, such as adjusting operational schedules, sealing leaks, or optimizing control settings. In cement plants, preliminary audits may highlight inefficient kiln operation, excessive fan use, or unoptimized grinding circuits (Thakare; 2018).

2.7.2.2 General (Standard) Audits

Standard audits involve quantitative measurements and structured analysis to gain a detailed understanding of energy consumption patterns. They often include measurements using power meters, temperature sensors, and flow meters, as well as energy balance calculations for major plant processes. In cement manufacturing, this may include assessing thermal energy usage in kilns, electrical consumption in mills, and energy losses in material handling systems**.** Findings from standard audits support medium-impact operational improvements and minor capital investments, bridging the gap between quick walk-through audits and detailed audits (Sharma et al., 2021).

2.7.2.2 Detailed (Comprehensive) Audits

Detailed audits are the most rigorous type, incorporating continuous monitoring, extensive data collection, and sophisticated technical and financial analysis. They quantify energy flows accurately, identify losses across all subsystems, and evaluate the financial viability of interventions using cost-benefit analysis, payback period, and ROI calculations. In cement plants, detailed audits may examine kiln heat losses, grinding mill efficiency, compressor performance, and waste heat recovery opportunities**,** providing management with actionable information to optimize both energy use and capital investment decisions (Muhammad *et al*., 2019).

2.7.2.3 Specialized and Investment-Grade Audits

Specialized audits focus on specific high-energy-consuming subsystems, such as compressed air networks, HVAC, lighting, or conveyors. Investment-grade audits expand on detailed audits by integrating rigorous financial modelling to justify large capital investments or energy performance contracts. They ensure interventions are both technically feasible and economically viable, giving confidence for high-value energy-saving projects (Science Direct Topics, 2024).

2.7.3 Importance of Energy Audits in Cement Manufacturing

Energy audits are indispensable in cement plants due to the high energy demands of clinker production, grinding, and auxiliary operations. They provide a comprehensive understanding of energy flows, identify inefficiencies, and recommend actionable solutions. Beyond cost savings, audits contribute to sustainability goals by reducing greenhouse gas emissions, supporting regulatory compliance, and promoting responsible energy management (Madlool, *et al*, 2018).

By integrating energy audits into plant operations and Energy Management Systems**,** cement manufacturers can establish a culture of continuous improvement, track performance against benchmarks, and ensure that energy efficiency initiatives are both technically and economically sustainable. In essence, energy audits are not just technical assessments; they are strategic instruments that enable organizations to optimize energy use, enhance operational efficiency, reduce environmental impact, and maintain competitiveness in energy-intensive industries (Palli, 2024).

2.8 Energy Performance Indicators and Benchmarks

Energy Performance Indicators (EPIs) are quantitative metrics used to evaluate, monitor, and optimize energy consumption in industrial operations. In cement manufacturing, where energy constitutes a significant portion of production costs often between 40–50% EPIs are critical for assessing operational efficiency, identifying inefficiencies, benchmarking performance, and guiding strategic energy management decisions (Madlool, *et al,* 2011; Fadare *et al*., 2025). Cement production is highly energy-intensive due to the thermal requirements of clinker production and the substantial electrical energy used in grinding, conveying, and auxiliary processes. EPIs provide a systematic framework for understanding energy consumption patterns and implementing effective energy-saving interventions.

2.8.1 Key Energy Performance Indicators

1. **Specific Thermal Energy Consumption (STEC):** STEC measures the amount of thermal energy required per tonne of clinker or cement, expressed in gigajoules per tonne (GJ/t). Efficient modern dry-process cement plants, especially those equipped with preheater and precalciner technology, typically achieve STEC values in the range of 3.4–3.5 GJ/t**,** whereas older or less optimized plants may consume significantly more (A Mokhtar & Nasooti, 2020; Sarfraz, 2023). Elevated STEC values may indicate heat losses in the kiln system, poor combustion control, or inadequate insulation, highlighting areas for potential energy recovery and efficiency improvements.
2. **Specific Electrical Energy Consumption (SEEC):** SEEC quantifies electricity usage per tonne of cement**,** typically measured in kilowatt-hours per tonne (kWh/t). In well-optimized plants, electrical consumption generally ranges from 110–120 kWh/t, with grinding operations accounting for a large portion of this demand (Scientific Reports, 2025). High SEEC values indicate potential inefficiencies in motors, grinding circuits, or auxiliary systems and provide insight into targeted optimization strategies.
3. **Process-Specific Indicators:** Detailed breakdowns of energy use by subsystem including raw milling, clinker grinding, and material handling help identify specific inefficiencies. For example, ball mills in the grinding stage can account for 4.5–25 kWh/t**,** depending on mill design, material hardness, and operational control (Moya, et al 2019). These process-

level indicators enable precise interventions to reduce energy consumption and operational costs.

4. **Comparative Performance Indices:** Benchmarking studies provide industry-standard reference values for energy performance, facilitating comparison across plants and regions. Global surveys indicate that optimized cement plants consume between 3.0–3.7 GJ/t of thermal energy and 110–120 kWh/t of electrical energy, while less efficient facilities exceed these values (UNIDO, 2019). In Nigeria, energy consumption often surpasses global benchmarks due to older technologies, reliance on fossil fuels, and grid instability, underscoring the importance of robust energy management practices (Moya, et al 2019).).

2.8.2 Benchmark Values and Interpretation

Benchmarking against industry best practices allows plant managers to identify efficiency gaps and prioritize corrective measures. Thermal energy benchmarks guide interventions such as waste heat recovery, improved kiln control, and insulation upgrades, while electrical benchmarks highlight opportunities in grinding system optimization, motor efficiency improvements, and process automation**.** Comparative analysis also enables evaluation of financial and environmental benefits, including reductions in operating costs and greenhouse gas emissions (Madlool *et al.,* 2011; Fadare *et al*., 2025).

2.8.3 Applications of EPIs

The application of EPIs in cement plants serves several critical functions:

i. **Baseline Establishment:** EPIs provide a historical reference point for energy consumption, which is crucial for measuring the impact of energy-saving measures over time.

ii. **Performance Tracking and Continuous Improvement:** Regular monitoring of EPIs helps evaluate the effectiveness of interventions and supports a culture of continuous energy management.

iii. **Investment Justification:** Quantified energy performance supports business cases for technological upgrades such as waste heat recovery, high-efficiency grinding systems, and alternative fuel integration**.**

iv. **Sustainability and Compliance:** EPIs are essential for energy reporting, sustainability initiatives, and compliance with environmental regulations by quantifying reductions in energy intensity and associated emissions (UNIDO, 2019; ResearchGate, 2025).

Table 2.3: Benchmark Energy Consumption in Cement Manufacturing

Energy Type	Typical Range (Global Benchmark)	Typical Range (Nigerian Context)	Remarks	References
Thermal Energy (STEC)	3.0 – 3.7 GJ/tonne of clinker	3.5 – 4.2 GJ/tonne of clinker	Reflects efficiency of dry-process kilns; higher values indicate heat losses or older technology.	(Madlool et al., 2011; UNIDO, 2019; Fadare et al., 2025)
Electrical Energy (SEEC)	110 – 120 kWh/tonne of cement	115 – 135 kWh/tonne of cement	Includes grinding, conveying, fans, and auxiliary systems. Higher values indicate inefficient motors or mills.	Fadare et al., 2025)
Specific Fuel Consumption	60 – 130 kg fuel oil equivalent/tonne clinker	70 – 145 kg fuel oil equivalent/tonne clinker	Indicates fuel efficiency in kilns; affected by fuel quality and kiln technology.	(Madlool et al., 2011; Research Gate, 2025)
Grinding Energy (Ball Mills)	4.5 – 25 kWh/tonne cement	5 – 28 kWh/tonne cement	Process-specific EPI; highlights potential for mill optimization.)	Sarfraz, 2023

2.9 Energy Performance Indicators and Benchmarks

Energy performance indicators (EPIs) are systematic metrics used to evaluate the efficiency of energy utilization in industrial production systems. In energy-intensive industries such as cement manufacturing, EPIs provide a quantitative framework for measuring the relationship between energy input and production output. They are particularly important for identifying inefficiencies, tracking performance trends over time, and supporting evidence-based decision-making in energy management. The use of standardized indicators allows for objective comparison across plants, technologies, and operational conditions, making EPIs a foundational component of energy audits and sustainability assessments within the cement industry (Worrell *et al.*, 2017).

In cement production, energy performance is commonly expressed through two primary indicators: specific thermal energy consumption and specific electrical energy consumption. Specific thermal energy consumption measures the amount of heat energy required to produce a unit mass of clinker and is typically expressed in megajoules per kilogram of clinker (MJ/kg clinker) or gigajoules per tonne of clinker (GJ/t clinker). This indicator reflects the efficiency of the pyroprocessing stage, which includes preheating, calcination, and clinker formation in the rotary kiln. Since thermal energy accounts for the largest share of total energy use in cement manufacturing, this indicator is critical for evaluating kiln performance and fuel utilization efficiency (Hasanbeigi, 2020).

Specific electrical energy consumption, usually expressed in kilowatt-hours per tonne of cement produced (kWh/t cement), is another key indicator used to assess electrical efficiency in cement plants. Electrical energy is predominantly consumed in raw material grinding, cement grinding, material transport systems, and large auxiliary equipment such as fans and compressors. Among these processes, cement grinding is often the most electricity-intensive operation. Variations in electrical energy intensity are influenced by factors such as mill type, grinding technology, equipment age, and process control strategies, making this indicator essential for identifying opportunities for electrical energy optimization (Moya *et al.,* 2019).

Energy performance benchmarks provide reference values derived from best-practice plants, industry surveys, and empirical performance studies. These benchmarks represent achievable energy consumption levels under optimized operating conditions and are used to evaluate whether a plant is performing efficiently or operating above expected energy intensity thresholds. Studies have shown that modern dry-process cement plants with multi-stage preheaters and precalciners generally achieve significantly lower energy intensities than older wet-process plants. Benchmarking against such reference values enables energy managers to quantify performance gaps and prioritize energy efficiency improvement measures (Zhang *et al*., 2021).

Beyond performance comparison, EPIs play a crucial role in continuous improvement and compliance with international energy management frameworks such as ISO 50001. Establishing baseline energy indicators and monitoring deviations over time allows cement plants to assess the effectiveness of energy conservation measures, technological upgrades, and operational changes. Furthermore, energy performance indicators support long-term strategic planning by informing decisions related to alternative fuels, waste heat recovery systems, and digital process optimization. As energy costs and environmental regulations continue to intensify, the systematic application of EPIs and benchmarks has become indispensable for achieving sustainable and competitive cement production (Li *et al*., 2022).

2.10 Gross and Process Energy Requirements

Energy consumption in cement manufacturing can be systematically categorized to enhance clarity in analysis and facilitate effective energy management. Two widely recognized classifications used in industrial energy assessment are the Process Energy Requirement (PER) and the Gross Energy Requirement (GER). These classifications help distinguish between energy directly consumed during production processes and the broader energy footprint associated with material inputs. Understanding this distinction is essential for comprehensive energy audits, as it enables researchers and plant managers to quantify energy use boundaries accurately and identify inefficiencies within and beyond the production system (Pardo *et al*., 2019).

The Process Energy Requirement (PER) refers to the total amount of energy directly and indirectly consumed within the operational boundary of the cement manufacturing process. This includes thermal and electrical energy used during raw material crushing, raw meal grinding, clinker production, cement grinding, and auxiliary operations such as material handling, lighting, and compressed air systems. PER focuses strictly on on-site energy use and excludes upstream energy associated with raw material extraction or transportation. As a result, PER is particularly useful for evaluating plant-level operational efficiency and for identifying process-specific opportunities for energy optimization (Madlool et al., 2018).

In contrast, the Gross Energy Requirement (GER) provides a more comprehensive measure of energy consumption by incorporating the Process Energy Requirement alongside the embodied energy of input materials. Embodied energy includes the energy expended during the extraction, processing, and transportation of raw materials, fuels, and additives prior to their arrival at the cement plant. GER therefore reflects the total life-cycle energy demand associated with cement production and is commonly used in sustainability assessments, life cycle analyses, and environmental impact studies. This broader perspective is increasingly important in evaluating the true energy and carbon footprint of cement manufacturing systems (Habert *et al*., 2020).

In many cement plants, particularly those with on-site limestone quarries and localized raw material sourcing, the difference between PER and GER is relatively small. This is because the energy associated with transporting raw materials is minimized, and most energy consumption occurs within the production process itself. Empirical studies have shown that under such conditions, PER and GER values tend to converge, making process-level energy efficiency improvements the dominant factor influencing overall energy performance. This characteristic is common in integrated cement plants operating within resource-rich locations (Benhelal *et al.,* 2021).

Distinguishing between PER and GER is critical for effective energy planning and policy formulation within the cement industry. While PER-based analysis supports operational decision-making and short-term efficiency improvements, GER-based assessment provides insights into long-term sustainability strategies, including supply chain optimization and material substitution. Together, these metrics form a robust analytical framework for comprehensive energy audits, enabling cement plants to balance production efficiency with environmental responsibility in an increasingly energy-constrained industrial landscape (Ogunjuyigbe *et al*., 2022).

2.11 Overview of BUA Cement Plant, Obu-Okpella, Edo State

The BUA Cement Plant is located at Obu-Okpella in Edo State, Nigeria, and is recognized as one of the largest cement manufacturing facilities in Sub-Saharan Africa. The plant is reported to be among the largest single cement production complexes globally, with a combined installed capacity of approximately 18 million metric tonnes per annum (MMTPA). Large-scale cement plants of this magnitude are strategically important due to their ability to achieve economies of scale, enhance production efficiency, and significantly contribute to national industrial development and infrastructure growth (Scrivener *et al*., 2018).

The Obu-Okpella plant is BUA Cement's first Greenfield cement project and represents one of the largest private sector investments in Nigeria outside the oil and gas industry. The project was engineered and executed by internationally renowned technical partners and constructed to meet global best-practice standards in cement manufacturing. The plant was officially commissioned in 2018, marking a major milestone in Nigeria's industrial expansion and reinforcing the role of private investment in strengthening domestic manufacturing capacity (Akinwale and Aladejare, 2022).

BUA Cement Plant operates three fully functional production lines. Line 1, whose erection commenced in 2012, was completed in 2015 and subsequently commissioned in 2017. Line 2 was completed and commissioned in 2018, bringing the combined production capacity of the plant to 12 MMTPA at that time. In 2022, Line 3, with an additional capacity of 6 MMTPA, was completed and formally commissioned, raising the total installed capacity of the plant to 18 MMTPA. The commissioning of Line 3 positioned BUA Cement Plant, Obu-Okpella, as the second-largest cement producer in Nigeria in terms of installed capacity (Obamuyi *et al.,* 2021).

The plant employs modern dry-process cement manufacturing technology across all production lines. Line 1 was constructed by a Danish engineering firm, while Lines 2 and 3 were built by Chinese contractors using contemporary industrial standards. Dry-process technology is widely regarded as the most energy-efficient cement production method due to its use of multi-stage cyclone preheaters and precalciners, which significantly reduce thermal energy consumption and improve heat recovery. This technological configuration enhances operational efficiency while minimizing fuel usage and environmental impact (Hasanbeigi, 2020).

In terms of fuel utilization, Lines 1 and 2 primarily operate on liquefied natural petroleum gas (LNPG), while Line 3 is designed to run on pulverized coal. In addition, the plant is supported by a 135 MW captive power generation facility, which operates on LNPG and coal alternately to ensure stable electricity supply. Diesel is maintained as a backup fuel for both kiln operations and power generation. The use of captive power generation is a common practice in energy-intensive industries in developing economies, where grid power supply may be unreliable or insufficient for continuous industrial operations (Emodi *et al*., 2020).

Raw material supply for the plant is secured through several high-quality limestone quarries located within close proximity to the facility. These quarries are estimated to have limestone reserves sufficient for over 100 years of operation, ensuring long-term production sustainability. Crushed limestone and corrective additives are transported from the quarries to the raw mix preparation zone using an extensive conveyor belt system measuring approximately 7.5 km in length. The use of conveyor systems reduces reliance on haulage trucks, lowers fuel consumption, and minimizes material handling losses, thereby contributing to improved energy efficiency and environmental performance (Benhelal *et al*., 2021).

The scale of operation, modern production technology, diversified energy sources, and integrated material handling systems make BUA Cement Plant, Obu-Okpella, an appropriate and robust case study for conducting a comprehensive energy audit. Evaluating energy performance at such a facility provides valuable insights into thermal and electrical energy utilization patterns, efficiency improvement opportunities, and best practices applicable to large-scale cement plants operating within Nigeria and similar developing economies (Olatunji *et al*., 2023).

2.12 Review of Related Studies

Energy auditing in cement manufacturing has been widely studied due to the sector's high energy intensity and substantial contribution to industrial energy consumption. Systematic energy audits provide an essential framework for identifying inefficiencies, quantifying energy losses, and recommending operational improvements. Studies indicate that clinker production and grinding operations are the most energy-intensive stages, highlighting the critical need for energy audits to optimize both thermal and electrical energy utilization (Emmanuel, 2023).

Oche Abigel Emmanuel (2023) conducted an energy audit on Line 1 of BUA Cement Plant, Obu-Okpella, using ETAP 12.6 and MATLAB Simulink/PSAT R2018a software. Load flow analysis revealed areas of electrical energy losses and opportunities for optimizing energy distribution across the plant. This study demonstrated the effectiveness of integrating simulation and modelling tools with traditional audits to improve plant performance and reduce energy wastage.

Nouman Ali Shah (2016) performed an energy audit in Pakistan on a cement factory and an educational building. The study assessed operational energy use and identified measures to optimize energy consumption, such as reducing idle equipment operation and improving process control. The results emphasized that targeted energy audits could substantially reduce operational costs while enhancing energy efficiency in both industrial and hybrid facilities.

Idukpaye (1996) carried out a detailed energy audit of West African Portland Cement Company, Shagamu Works, a wet-process plant. The study quantified energy requirements for each production stage, including primary crushing, raw material milling, clinker production, and cement grinding. The results of the audit are summarized in Table 2.4.

Table 2.4: **Result of Idukpaye's Energy Audit of West African Portland Cement plc, Shagamu Works**

Process	Process Output (dry, tph)	Process Stage (t/t)	Direct Energy Requirement (kWh/t)	Fuel Energy (kJ/t)
Dewatering	1.78	-	-	-
Primary Crushing	281.45	2.34	1.193	-
Stone Transport	281.45	2.34	0.234	-
Secondary Crushing	242.84	2.02	3.07	-
Raw Material Milling	242.84	2.02	21.62	-
Slurry Transport to Basin	242.84	2.02	3.08	-
Slurry Storage, Blending, Transport to Kilns	209.94	1.74	2.93	-
Clinker Production	100.68	0.84	26.88	7,495,611
Clinker/Gypsum Handling	12.24	1.01	0.53	-
Cement Milling	120.32	1.00	2.38	-
Cement Transport to Silos	120.32	1.00	2.38	-
Cement Dispatch	120.32	1.00	1.65	-

Note: tph = tons per hour; t/t = tons of process material per ton of cement

The Process Energy Requirement (PER) per ton of cement for WAPCO Shagamu Works is summarized in Table 2.5, highlighting that clinker production accounts for the highest proportion of energy use.

Table 2.5: Process Energy Requirement per ton of Cement for WAPCO, Shagamu Works

Component	Electrical Power (MJ/t cement)	Fuel Energy (MJ/t cement)	Total (MJ/t cement)	% PER
DER	465.48	6296.31	6761.79	99.56
IER	29.65	-	29.65	0.44
PER	495.13	6296.31	6791.44	100.00
% PER	7.29%	92.71%	100.00%	-

Similarly, Lawal's energy audit of WAPCO Ewekoro Works calculated the PER at 4976.73 MJ/t cement (≈4.9 MJ/kg cement), reinforcing the observation that clinker production is the most energy-intensive process, and energy auditing is critical for cost and environmental optimization (Lawal, 2008).

Gholipour Khajeh et al. (2014) conducted an energy audit on a cement plant in Iran, proposing strategies to reduce energy losses in thermal and electrical systems. Table 2.6 summarizes the annual heat energy saving potential for multiple plants in Iran, demonstrating the substantial savings achievable through energy-efficient practices.

Table 2.6: Annual Heat Energy Saving Potential Compared to the Best practices in Iran

Factories	Heat Energy Saving Potential (MJ/kg clinker)	Heat Energy Saving Potential (%)	Heat Energy Saving Potential (MJ)	Heat Energy Saving Potential (BOE)
Tehran 4th	3.5	0.2	109,030,800	18,751
Tehran 7th	3.71	0.41	224,907,140	38,679
Ardebil	3.48	0.18	123,894,360	21,307
Kurdistan	3.3	0	0	0
Hamadan	3.58	0.28	174,531,840	30,016
Total	-	-	632,364,140	108,753

Energy intensity studies also focus on electrical energy consumption. For example, the total electrical energy intensity and saving potential for Iranian plants are shown in Tables 2.7 and 2.8, indicating the lowest electrical energy intensity of 103 kWh/ton in Kurdistan Cement Plant, which serves as the benchmark for potential savings (Irekefe, 2024).

Table 2.7: **Total Electrical Energy Intensity Iranian plant**

Factories	Cement Production (ton/year)	Electrical Energy Intensity (kWh/ton cement)
Tehran 4th	796,310	126.3
Tehran 7th	793,980	117.5
Ardebil	1,089,500	136.4
Kurdistan	1,024,094	103.0
Hamadan	1,094,850	115

Table 2.8: **Annual Electrical Energy Saving Potential Iranian plant**

Factories	EEI (kWh/ton cement)	EE Saving Potential (kWh/t cement)	EE Saving Potential (kWh)	EE Saving Potential (BOE)
Tehran 4th	126.3	22.5	13,298,805	8,233
Tehran 7th	117.5	13.7	8,371,303	5,183
Ardebil	136.4	32.6	22,449,534	13,899
Kurdistan	103.8	0.0	0	0
Hamadan	115.0	11.2	6,533,520	4,045
Total	-	-	50,653,161	31,360

Other studies, such as those by Thakare (2018), Kabir et al. (2010), and Anantharaman (2015), have also reinforced that energy auditing and benchmarking can identify inefficiencies in pyro-processing units, fans, compressors, and material transport systems, thereby allowing practical interventions for energy and cost savings. The integration of software tools, field measurements, and benchmarking ensures audits are both comprehensive and effective (Thakare, 2018; *Kabir et al.*, 2010; Anantharaman, 2015).

In conclusion, energy auditing in cement plants is an essential mechanism for enhancing operational efficiency, reducing costs, and supporting sustainable industrial practices. The reviewed studies, including Nigerian, Iranian, Indian, and Kenyan contexts, collectively illustrate the importance of plant-specific audits**.** These audits allow for benchmarking against best practices and provide actionable insights for both electrical and thermal energy optimization in facilities such **as** BUA Cement Plant, Obu-Okpella (Oche Abigel Emmanuel, 2023).

2.13 Research Gaps

A careful review of existing literature on energy auditing in cement manufacturing highlights several important gaps that this study seeks to address, particularly in the context of BUA Cement Plant, Obu-Okpella. One major limitation in past research is that most studies have focused on either electrical or thermal energy, rather than considering both together in a comprehensive analysis. For instance, Oche Abigel Emmanuel (2023) conducted an electrical energy audit on Line 1 of BUA Cement Plant using ETAP and MATLAB, which provided valuable insights into electrical load distribution. However, thermal energy use in critical processes such as clinker production, preheating, and grinding was not examined. Without this integrated perspective, it is difficult to fully understand the plant's overall energy performance or identify opportunities for broad-based efficiency improvements.

Another gap is the lack of localized, context-specific data for Nigerian dry-process cement plants. While international studies offer useful benchmarks and insights into energy intensity and potential savings (Gholipour Khajeh et al., 2014; Irekefe, 2024), the findings are not directly transferable to Nigerian plants due to differences in fuel types, operational practices, infrastructure, and environmental conditions. As a result, there is limited knowledge of actual energy consumption patterns, specific energy consumption (SEC), and operational inefficiencies in Nigerian plants, which makes it challenging to develop effective, evidence-based strategies tailored to local conditions.

A further gap is the absence of holistic, plant-wide audits that cover all production lines and auxiliary systems. Many previous studies have focused narrowly on individual units or processes, overlooking cumulative energy losses and the interconnections between systems such as conveyors, pumps, fans, lighting, and captive power generation. In addition, benchmarking against best-practice standards has rarely been applied in the Nigerian cement sector, limiting the ability to objectively assess performance and identify where improvements can have the greatest impact. A comprehensive, plant-wide audit with benchmarking is therefore essential to uncover meaningful opportunities for energy savings and operational optimization at BUA Cement Plant.

These gaps the need for integrated analysis of electrical and thermal energy, the lack of locally relevant empirical data, and the absence of comprehensive plant-wide audits with benchmarking underscore the importance of this study. Filling these gaps will allow for a clearer understanding of energy use across all processes, help identify inefficiencies, and support the development of practical strategies to improve operational efficiency, reduce costs, and promote sustainable energy management at BUA Cement Plant, Obu-Okpella.

CHAPTER THREE

METHODOLOGY OF THE STUDY

3.1 Description of Bua Cement Plant

3.1.1 Site Location

The site location of the Bua Cement Plant (BCP) is at Obu-Okpella Edo State, Nigeria, and the plant is involved in the construction and operation of a Greenfield cement. It's positioned along the Abuja-Okene expressway. The factory's location is also defined by latitude 7°016' North and longitude 6°020' East

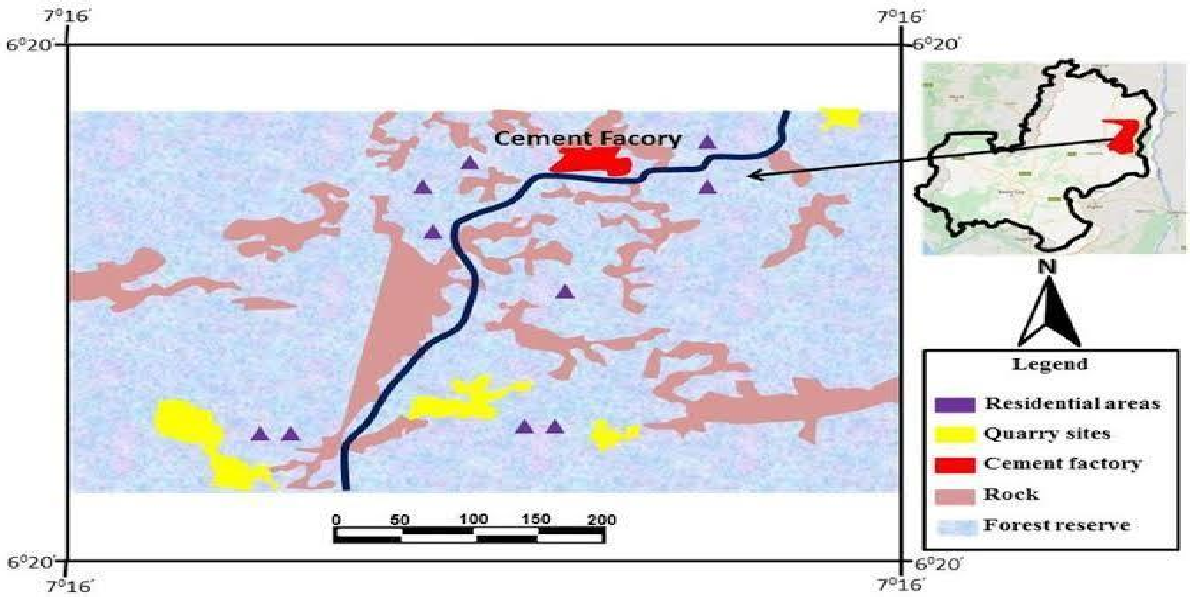

Figure.3.1 Bua Cement Factory map location

Source: Bua Cement plant

The plant's location KM 164, Benin-Okene express way, Okpella affords access to vast deposit of limestone. Its limestone quarries has associated 7.5 km conveyor belt for conveying crushed limestone and additives; a 13m high dam impounding a reservoir with a total storage capacity of 5.1 million m^3.

The site is also strategic: The Bua Cement factory produces most of the cement required in the south-south, middle belt, North Eastern and the North Central states of Nigeria. The production of cement at Bua reduces the cost of cement occasioned by the high cost of transport.

3.1.2 Source of Gas Supply

The cement factory is equipped with a 90 MW gas turbine plant with a delivery operational capacity of 70MW to generate its own electric power for use by the cement kilns auxiliaries and other production processes. There are also Wasilla generator of about seven (7) with 12 MW Capacity each bring the combined rated capacity to 84MW Operating capacity each is 10MW with a delivery capacity of 70MW. The natural gas supply originates from a tie-in point on the Nigeria Gas Company (NGC) Oben through Okpekpe to Obu-Okpella.

Two types of gas are being supplied: the associated and non-associated gas. The associated gases are ethane, propane, and butane, while the non-associated gas is methane. The gas supply line is a 154 km gas pipeline. The gas pipeline supplies 60 million scf (Mmscfd) to the two plants, with a total of 120 Mmscfd of natural gas (considering 100% capacity of the two lines of the cement plant and four gas turbines in operation) as the primary fuel for electricity generation and kiln auxiliaries.

Consequently, the gas pipeline system is designed to achieve a maximum delivery of 120 Mmscfd. The design pressure and temperature of Oben-Obu Okpella pipeline is 100 bar and 50^0C respectively whereas the maximum allowable operating pressure is 32 bar with an operating temperature of 35^0C. Line Break Valves (LBV) installed at approximately every 30 km and upstream/downstream of river crossings to minimize the release of HC incase of line rupture. Slam shut valve is provided at tie-in to Oben- Obu Okpella Gas Pipeline to perform the same function as LBV. ESD system at Bua cement plant pressure reducing and metering facility. Over 154 km of right-of-way (ROW) is acquired for the pipeline route.

3.1.3 Mining Operation

Mining operations carried out include drilling, blasting, crushing, hauling and transportation, activities among others.

A conceptual mining plan based on technical and economic considerations is put in place to ensure a sustainable mining operation. The entire deposit is mined up to 45m depth. The block is mined section by section, so that as one section is exhausted, it is refilled by waste generated from adjacent section. The mining operation is in phases.

3.2 Data Collection

In order to achieve the aim and objective of the study the methodologies employed in this research involved reviewing the objectives, making frequent visit and contact with the company representatives in the production and process department located at BCP to obtain the existing data of all the energy systems available and its' quarry site.

Data was then analyzed to determine the energy saving potentials that are obtainable at the plant. In an attempt to investigate the energy usage vis-a-vis heat and electrical energy intensities in the raw mill, processing of clinker and consequent production of cement, collected materials and energy data were done through the following sources:

3.2.1 On-site visit and detailed study of all unit Operations in the plant

A physical walk was made through the plant to inspect every major processes, units and utility system to understand how energy is used, lost, and controlled. Table 3.1 shows the record taking during the walk through visit revealing the plant infrastructural description and its design capacity

3.2.2 Oral interviews.

During the visit oral interview was conducted among the production and processing manager, staff of the power plant and gas plant.

3.2.3 Central Control Room (CCR)

A visit to the Central Control Room which is the operational nerve of a facility. It's where operators continuously monitor, control and optimize all critical system from a single centralized location**.** Data were collected from CCR as presented in appendix 1

3.2.4 Secondary Data source from the plant

Secondary data source from the plant were collect as well with the assistance from the process manager as tabulated in appendix ix

Data obtained in Table 3.1was from going round the respective energy equipment of the Bua plant. Tables 3.4 to 3.7 in Appendix I show the report of the amount of power (energy) consumed in kWh, running hours, production in metric tons (Mt), and output in tons per hour (tph) for three months each Data were obtained from the processing unit of Bua cement plant.

The reports were obtained by dividing the electrical energy consumption by the amount of process materials consumed. KWh/ton cement was obtained by dividing the electrical energy consumption (kWh) at each process stage by the amount of cement produced for the period.

Table 3.1 Bua cement Plant Infrastructural Description and its design capacity

UNITS	MATERIALS	EQUIPMENT	PROCESS LINE	TYPE	CAPACITY	UNITS
Raw Materials Preparation	Limestone	Primary Crusher	Line 1	Jaw Crusher	770 tph	1
			Line 2	Gyratory Crusher	1000 tph	1
			Line 3	Gyratory Crusher	1000 tph	1
		Secondary Crusher	Line 1	Cone Crusher	770 tph	1
			Line 2	Cone Crusher	1000 tph	1
			Line 3	Cone Crusher	1000 tph	1
	Laterite		Line 1	Roller Crusher	450tph	1
			Line 2	Roller Crusher	400tph	1
			Line 3	Roller Crusher	400tph	1
	HG Limestone / Gypsum / Iron Ore	Additive Crusher	Line 1	Hammer Crusher	500t/h	1
			Line 2	Hammer Crusher	300t/h	1
			Line 3	Hammer Crusher	300t/h	1
Raw Material Storage		Raw Mix	Line 1	Mixed / Longitudinal	30000t	2
			Line 2	Mixed / Longitudinal	30000t	2
			Line 3	Mixed / Longitudinal	30000t	2
		HG Limestone	Line 1	Cone	1500t	2
			Line 2	Cone	1500t	2
			Line 3	Cone	1500t	2
		Gypsum	Line 1	Cone	1500t	2
			Line 2	Cone	1500t	2
			Line 3	Cone	1500t	2
		Iron Ore	Line 1	Cone	1500t	1
			Line 2	Cone	1500t	1
			Line 3	Cone	1500t	1

UNITS	MATERIALS	EQUIPMENT	PROCESS LINE	TYPE	CAPACITY	UNITS
Raw Milling		Raw Mill Plant	Line 1	Vertical Roller Mill	465 tph	1
			Line 2	Vertical Roller Mill	466 tph	1
			Line 3	Vertical Roller Mill	467 tph	1
Sintering / Burning		Pyro Process	Line 1	Precalciner & Grate Cooler	6000 tpd	1
			Line 2	Precalciner & Grate Cooler	6000 tpd	1
			Line 3	Precalciner& Grate Cooler	6000 tpd	1
		Finish Milling				
			Line 1	Ball Mill	200 tph	2
			Line 2	Vertical Roller Mill	200 tph	2
			Line 3	Ball Mill	200 tph	2
		Packing Plant	Line 1	Rotor Packer	120 tph	6
			Line 2	Rotor Packer	120 tph	6
			Line 3	Rotor Packer	120 tph	5

3.3 Direct and Indirect Energy Requirement,

Direct Energy Requirement (DER) include pumps, motors, compressor, draft fans, blowers and other plant equipment and Indirect Energy Requirement (IER) which include lighting, cooling, administrative buildings, canteens, housing estate, clinic etc.

DER for both electrical and thermal is calculated using energy data such as factory power, fuel consumption and total annual cement produced from equation (3.1)-(3.3)

$$\text{Direct Electrical Energy Requirement(DEER)} = \frac{Total\ factory\ power}{\text{Total cement produced per annual}} \quad (3.1)$$

$$\text{Direct Thermal Energy Requirement (DTER)} = \frac{Total\ fuel\ consumption}{\text{Total cement produced per annual}} \quad (3.2)$$

$$\text{Indirect Electrical Energy Requirement(IEER)} = \frac{Total\ housing\ power}{\text{Total cement produced per annual}} \quad (3.3)$$

Process Electrical Energy Requirement is the sum of Direct Electrical Energy Requirement + Indirect Electrical Energy Requirement

Process Electrical Energy Requirement (PEER) = DEER + IEER (kWh/ton of cement) (3.4)

Process Thermal Energy Requirement (PTER) = DTER + ITER (MJ/Kg clinker) (3.5)

3.4 Kiln Shell Surface Temperatures

Radiation and convection surface losses were calculated from the surface temperatures. An electronic type of radiation pyrometer (infrared thermometer) is commonly used to measure the surface temperature of the kiln by dividing the entire length (surface area) of the kiln into segments of 1m each and a good number of temperature readings taken at each segments across the entire kiln length with the aid of the infra-red thermometers over a period of 24hours (two hours interval). However, at Bua Cement Plant the temperature readings were collected from the central control room why radiation and convection heat loss were calculated using the formula provided.

3.5 Calculation of Heat Losses

The heat losses comprise the convection, radiation from the kiln surface, preheater and the heat Losses due to the cooling water at roller bearings.

3.5.1 Radiation and Convection Heat Losses

The radiation and convection heat losses could be calculated using equations 3.6 and 3.7 at ambient temperature of 30^{o}C.

3.5.2 Heat Loss through the Outer Shell (Surface Loss) by Convection and Radiation

The surface heat loss consists of radiation and convection. SmidthFL using the formulas developed by ZurStrassen (www.flsmidth.com).

As it appears in a cement plant is usually a combination of radiation and convection calculated using equation (3.6) and (3.7)

Radiation (Q) = $e\,\sigma\,A\,[T^4 - T^4_\phi]$ (3.6)

Convection (q) = $h_c\,A\;\Delta T$ (3.7)

Where, T, T_ϕ, e, σ, A, h_c and ΔT are *surface temperature of the kiln shell (k), ambient temperature of the surrounding air (k),* emissivity of the surface, Stefan Boltzmann constant 5.67×10^{-8}, Surface area of the kiln shell, the convective heat transfer coefficient and the temperature difference of kiln surface and ambient air respectively.

$h_c = Nu\,k/L$ where Nu is Nusselt number, k is thermal conductivity of air which varies with temperature and pressure and L is characteristic length of kiln e.g. diameter

If the measured surface is exposed to wind above 3m/s, the convection is called forced convection (F.CON) is estimated using equation (3.8)

F.CON = $28.03 \times [T \times T_\phi]^{-0.351} \times V^{0.805} \times D^{-0.195} \times [T - T_\phi]$ *kcal/hm²* (3.8)

Where, V and D are the wind speed (m/s) and *the diameter of measure kiln (m).*

Radiation loss can be obtained from the Stefan – Boltzmann law given by the equation (3.9):

Radiation = $e \times \sigma \times A\,(T^4 - T^4_\phi)$ (3.9)

Where: *e, A, σ are emissivity of materials, surface area and Stefan – Boltzmann constant* ($5.67 \times 10^{-8}\ W/m^2\,K^4$)

3.6 Performance Efficiencies, Utility and Reliability Factors

The performance efficiencies, utilities and reliability factors of Bua cement were calculated using the design parameters from Table 3.1 and the cumulative production report for the year on Table 4.1

Percentage Efficiency is calculated by dividing the actual production rate by the designed (or expected) production rate.

*Utility factor (UF)***:** This indicates how the use of the plant is maximized and is given by the ratio of the running time to the total time available.

Reliability factor (RF) is obtained by dividing the running time by the sum of the incident time and the running time.

Output: And to get output in tons per hour equation (3.10) was estimated.

$$. \ Output(Tph) = \frac{Producion\ (mt)}{\text{Runing time(h)}} \tag{3.10}$$

3.7 Energy Analysis

In order to determine the energy saving potential of Bua, the total energy consumption for the year must be determined it will be necessary to compare the energy intensity of the factory based on energy consumption with other existing plants in the world.

3.8 Evaluation of Energy Intensities

The formula for evaluating the two kinds of energy indicators is as follows:

3.8.1 Electrical Energy Intensity (EEI)

The electrical energy intensity in a cement factory is the total electricity consumed per the total unit produced in tons. $EEI = \frac{\underline{Total\ electricity\ consumed\ (mwh)}}{Total\ unit\ produced(tons)}$ (3.11)

Using equation 3.10 to calculate electrical energy intensity at various operations at the plant include the following

1. Energy Intensity in Crusher
2. Energy Intensity in Raw Material Mill
3. Ratio of conversion material to one-ton clinker (1.6ton of material to 1ton clinker)
4. Energy Intensity in kiln
5. Percent of additives (negligible)
6. Energy Intensity in cement mill
7. Energy Intensity for additives production (Negligible)
8. Energy Intensity in packing

3.8.2 Heat Energy Intensity (HEI)

HEI in cement factories is calculated based on total thermal (heat) energy consumption in the kiln per annual clinker production using equation (3.12) (Bokaian, 1998)

$$\text{HEI (MJ/kgcl)} = \frac{\text{HEC}}{\text{AP}} \tag{3.12}$$

Where: *HEC and AP are Total Heat Energy Consumption (MJ) and Annual Production of clinker at the Kiln (Nm^3/ kg)..*

1. Evaluation of Electrical Energy

The electrical energy output in kWh is obtained by multiplying the rated power of the electrical motor, *p* in kW with the corresponding hours of operation *t*, the motor efficiency, ζ is assumed to be 80%. Fadare, *et al* (2025)

$$E_P = \zeta pt \tag{3.13}$$

Where: *E_P, ζ ,p, t are the Electrical energy power output, Motor efficiency(%,)rated power of electrical motor(W) and Hours of operation (hour)*

2. Evaluation of Thermal Energy

The thermal energy input, E_{fu} was calculated based on quantity of fuel used for burning and for generation. The quantity of fuel *W* in litre is converted to Joule, *J* by multiplying the quantity consumed by corresponding calorific value of fuel. As presented in equation (3.14)

$$E_{fu} = CV_{fu}W \tag{3.14}$$

Where, *E_{fu} , CV_{fu} and W are the Thermal energy input (J), Calofic value of fuel (J/I)and Volume of fuel (l) respectively*

3.9 Identification of Weak Point Areas and Energy Losses through Heat Balance

3.9.1 Heat balance is the equilibrium condition in which the amount of heat energy entering a system equals the amount of heat energy leaving that system. This concept is crucial in understanding how systems maintain their temperature and energy distribution.(Moren *et al 2024*

3.9.2 Weak point and losses in the plant

Heat energy balance can be used to estimate the weak points and losses that occurred in the plant. The weak points that can be highlighted during the heat balance process are air leakage, deficiency in burning conditions, loss through the sides and condition of the refractory lining, recovery efficiency of the cooler, efficiency of heat exchanger, problems of the volatility process and recycling of dust in the towers, failure in kiln operation and problems associated with deficient raw ix properties.

3.10 Principle for Conducting Heat Balance

The principle employed to conduct the heat balance of the plant are itemized as follow:

1 Choosing the limits within which the heat balances will be conducted

2 Measuring total heat in and total heat out

3 Recording all the process control parameters

4 Establishing a mass balance

5 Establishing an air balance

6 Establish the final heat balance

3.10.1 Stages of the Heat Balance

Estimating the mass balance for the materials input (raw mix) via the vertical roller mill to the material output (clinker) at the kiln outlet is the first stage in conducting the heat balance. The air balance which comprises the primary, secondary and tertiary air is analyzed next and the results of both the mass and air balance are used to conduct the heat balance. . It is therefore, pertinent to recall that:

1. The cement kiln is an integrated system involving several sub-systems to preheaters and precalciner, the feed before the rotary kiln, cool the clinker after combustion in the rotary kiln, prepare the fuels and fire them in the kiln, and vent and clean the exhaust gases generated in the kiln.
2. The cooler transfers the heat from the clinker to the combustion air. It is difficult to produce a sufficiently hot flame in the kiln unless the combustion air is pre-heated. The hot air thus passing into the kiln is referred to as secondary air as distinct from the primary air (10 – 15% total combustion air) which conveys the fuel into the kiln through the firing pipe. In more efficient kiln systems (in which fuel usage, and therefore combustion air usage, is reduced) there may be additional hot air available for other purposes, and this is referred to as tertiary air.

3.11 Procedure for Evaluating Mass Balance

In order to evaluate the mass balance for production of 1kg of clinker which is the end product of the kiln the theoretical amount of raw mix required to produce 1kg of clinker as presented in equation (3.9).

$$\text{Raw mix to clinker} = \frac{100}{100 - L.O.I} \qquad (3.15)$$

Where: *L.O.I is the Loss on Ignition of raw mix.*

(LOI) is common and widely used method to estimate the organic and carbonate content of sediments.

The theoretical value must be added to the amount of dust carried off by the waste gases at the top of the heat exchanger tower and reintroduced with the theoretical raw mix.

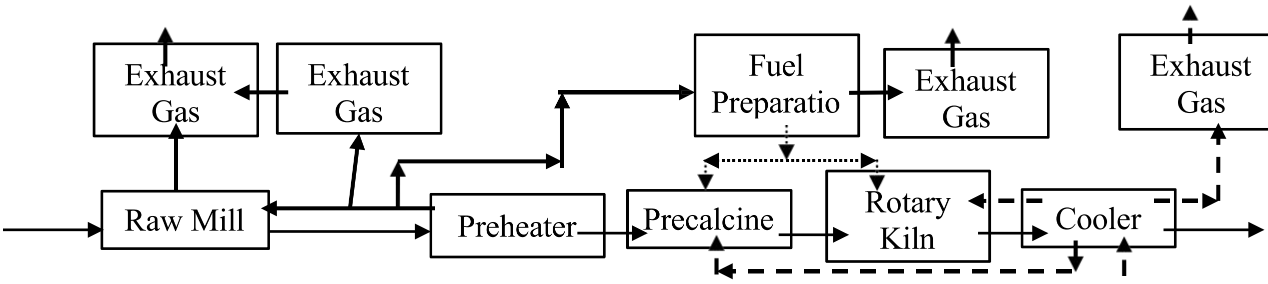

Figure 3.2 Mass and Energy balance of the Pyro processing

Meanwhile, in defining any mass balance of an industrial process it is necessary to define the system boundaries to determine which sub-systems will be included in the balance, and where the material flows will be deemed to cross the boundaries and flow into and out of the system.

Figure 3.2 illustrates the mass and energy balance of the pyro processing, which begins with the material flowing on through the preheater, precalciner, rotary kiln and exiting via the cooler. The exhaust gases from the preheater are ducted to the raw mill to dry the raw materials and then to the exhaust gas cleaning in the precipitator or bag filter. Cooling air is blown into the cooler from atmosphere. Combustion air is drawn from the cooler as secondary air for combustion in the main burner flame (of the rotary kiln) and separately via the tertiary air duct to the precalciner for combustion as tertiary air. More air is required to cool the clinker than is needed for combustion in the kiln main burner and precalciner and the excess air is separately exhausted to its own gas cleaning.

To determine the absolute mass balance of a cement kiln, such as during guarantee trials the clinker has to be weighed in trucks over a weighbridge. For day to day purposes, the clinker produced is calculated from the amount of feed and the loss on ignition (CO_2) content of the feed. Thus,

Tones clinker = Tones feed x $(1 - L.O.I_{feed})$ (3.16)

3.12 Air Balance

Air balance can be determined by using the air measurement and the fuel throughput and waste gas analysis at the kiln exit.

1. From air measurement: The secondary air is obtained by subtracting the tertiary, primary (dry) and exhaust air from the air blown under the grates.

Secondary Air =

AIR BLOWN OR RECOVERED – (TERTIARY AIR + PRIMARY AIR + EXHAUST AIR) i.e.

$S_a = B_a - [T_a + P_a + E_a]$

$S_a = C_a - [P_a + T_a]$ (3.17)

Air Blown or Recovered =

TERTIARY AIR + PRIMARY AIR + EXHAUST AIR + SECONDARY AIR

i.e. $B_a = T_a + P_a + E_a + S_a$ (3.18)

The volume of excess cooling air exhausted from the cooler or estimated from the difference between the total air blown into the cooler and the combustion air requirements of the fuel burnt in the main burner and the precalciner.

i.e. $B_a = E_a + S_a + P_a + T_a$ (3.19)

2. From fuel throughput - Fuel analysis and analysis of waste gas at the kiln exit- according to the leakages which are impossible to measure, the best way to determine secondary air flow-rate is from the total combustion air calculation.

Total Combustion Air = calculated secondary air + primary air from burner pipe + air intake through hood. i e. $C_a = S_a + P_a + T_a$ (3.20)

Hence:

Calculated Secondary Air = total combustion air – (air intake through hood + primary air from burner pipe)

i.e. $S_a = C_a – [T_a + P_a]$ (3.21)

where P_a, S_a, C_a, H_a, T_a, E_a *and* B_a *are primary air* $_{(Dry)}$ *,Secondary air, Combustion air, Hot air, Tertiary air, Exhaust air and Air blown or recovered respectively.*

Decarbonation of the kiln: is to remove the volume of carbon dioxide CO_2 from the combustion chamber of the kiln (Raw mix + CO_2). Volume of CO_2 of De-carbonation (Combustion + De-carbonation) will amount to Total Neutral Dry waste gases

The sum of Combustion Neutral Waste Gases (CNWG) plus CO_2 from de-carbonation gives the Total Neutral Dry Waste Gas (TNDWG). As reflected in equation (3.22)

C. N. W. G + DECARBONATION = TNDWG (3.22)

By addition of combustion & dehydration waste, we have Total Neutral Wet Waste Gas (TNWWG).

Air Excess: Combustion Air Excess is oxygen (O_2)at the kiln discharge and total dry and wet waste gases and total air of combustion given by the equation (3.23)

Neutral Air of Combustion (N.A.C) + Combustion Air Excess (C.A.E) =Total air of combustion (T.A.C)

i.e. N.A.C. + C.A.E. = T.A.C (3.23)

3.13 Calculation of Calorific Values, Combustion Gases and Combustion Air

Calorific values were obtained by using mass fraction of the natural gas constituents with the heat of combustion of natural gas at 25 ^{O}C and constant pressure.

Using R_0 = 8.3144kJ/kgk (the universal gas constant)

The value of R is 1.17832KJ/KgK

$$d=PM/RT \quad (3.24)$$

Where, d, P, M, R, and T are density, Pressure at STP, molar mass of the gas mixture, the ideal gas constant and standard temperature (k) respectively.

3.14 Economic Evaluation of Energy Consumption Cost in the Production of Cement.

BUA cement's energy cost is a representation of the total production cost.

The electricity tariff for Band A customers for the year 2024 was N225/kwh, a minimum of 20 - 24 hours of electricity per day

The price of diesel was N1462.98 per litre

The Nigeria Midstream and Downstream Petroleum Regulatory Authority (NMDPRA) gave the price of natural gas for commercial users as $2.92 MMBTU.

The combination of rising electricity tariffs, increased gas prices, and higher diesel prices has dramatically driven up the energy costs for cement manufacturers for the year 2024.

3.14.1 Estimation of Energy Cost

The analysis of average cost per tonnage is ₦225/ton based on electrical energy from the national grid and the gas turbine power plant, were estimated as follows:

Energy = power x time (3.25)

Electrical Energy Cost = energy used x kWh charges (3.26)

$$Q_{In} = Q_{useful} + Q_{Losses} \quad (3.27)$$

$Where\ Q_{In}$ is total Energy in , Q_{useful} is useful energy, and $Q_{Losses}\ is\ energy\ loses.$

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Electrical Energy

From the BUA Cement plant, the result obtained for the following energy consuming equipment of the cumulative production report in metric tons (Mt) and power consumption in kilowatt hours (kWh), running hours (h), and output in tons per hour (tph) is shown in Table 4.1. See Appendix I for more details.

From table 4.1, the running time for each equipment is estimated in a chat in figure 4,1 to represent the energy being consumed by these equipment as running time is synonymous to energy consumption.

From these table 4.1 the production (Mt), power consumption (kWh) and output (Tph) is estimated in a graph chat in figure (4.2),(4.3)and (4.4) respectively.

TABLE 4:1 Cumulative Production and Power Consumption Report Year 2024

S/NO	Equipment	Running hours (h)	Production(Mt)	Power consumption (kWh)	Output (Tph)
1	Crushers (1, II, &III) & ETS/Stacker/Recl. for line I, II, & III)	18,704.41	16,901,640	41,332,457	903.62
2	Raw mill (I, II&III)	23,818.06	15,860,013	261,575,910	665.88
3	Kiln (I, II& III)	42,171	9,825,933	211,053,826	233.00
4	Cement Mill (I,II,III,IV,V & VI)	78,910	11,515,875	517,163,020	145.94
5	Parking plant I,II &	186,043	16,149,562	17,364,106	86.81
6	Miscellaneous	8,760	9,203,005	21,418,671	1051.57

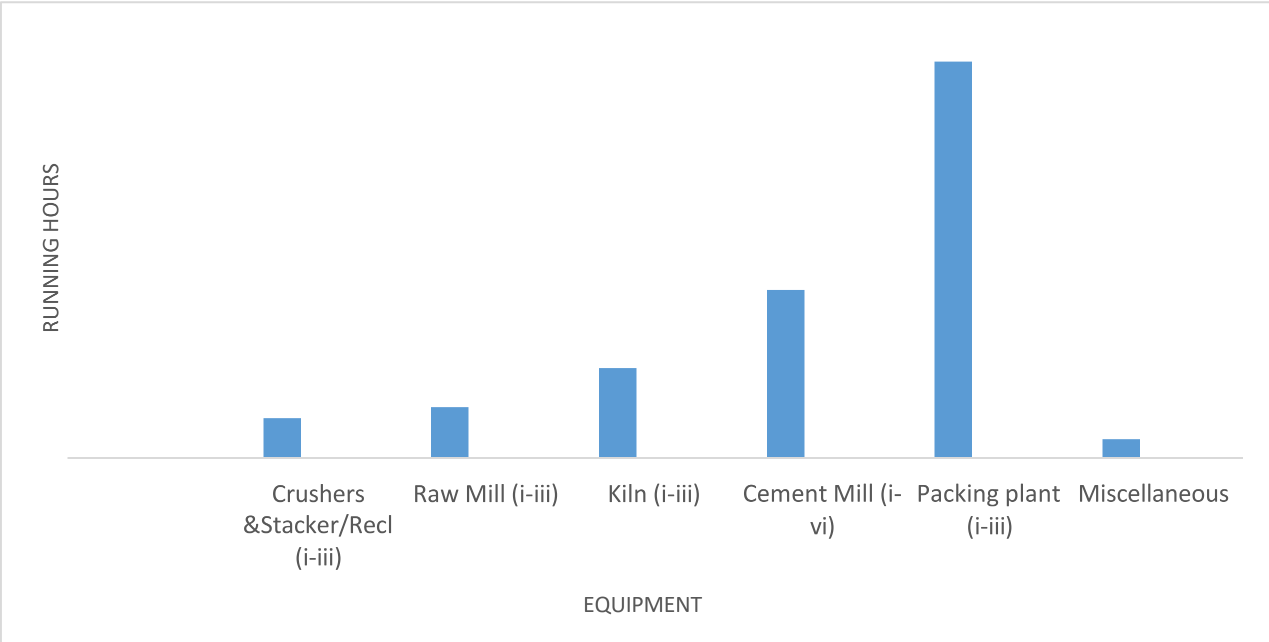

Figure 4.1 Running time versus Equipment

From figure 4.1, the packing plant has the most running hours in the plant followed by the cement mill and the kiln were electrical energy is being utilized.

.

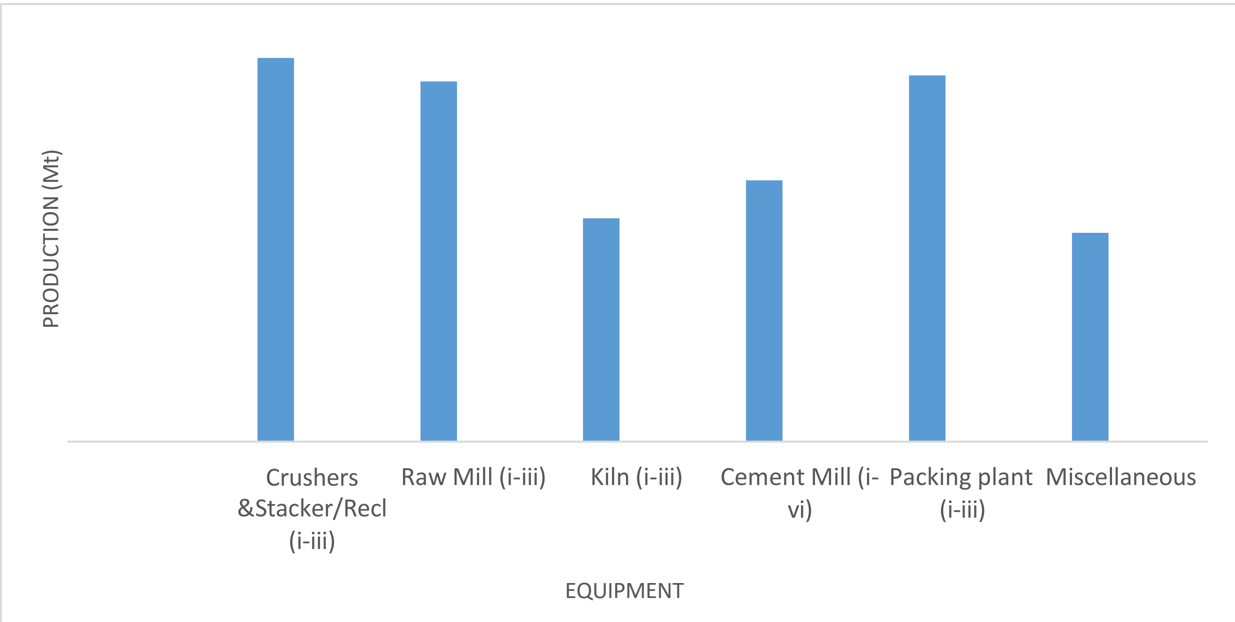

Figure 4.2 Production (Mt) versus Equipment

From figure 4.2 the production rate of these equipment indicates the amount of energy consumed by these equipment. The crusher is producing the raw materials needed for the cement process.it has a highest production rate, the packing plant has a higher production rate, to ensure finish product is delivered. The raw mill, cement mill and the kiln are not left out.

The power consumption rate of the cement manufacturing process of the varous equipment and section of the plant is estimated in figure 4.3 and the output of these equipment is indicated in figure 4,4

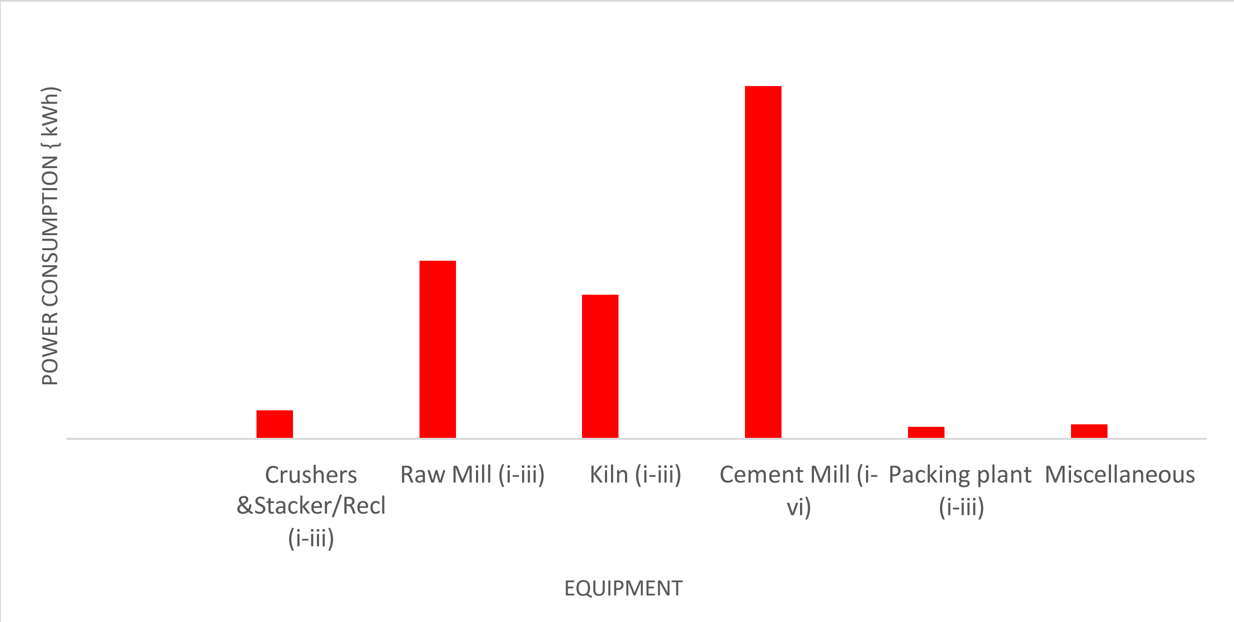

Figure 4.3 Power consumption versus Equipment

From the data collected in table 4.1, figure 4.3, indicates the cement mill consume mostly the electrical power next is the raw mill. While the kiln consume mostly the thermal power in the cement manufacturing process.

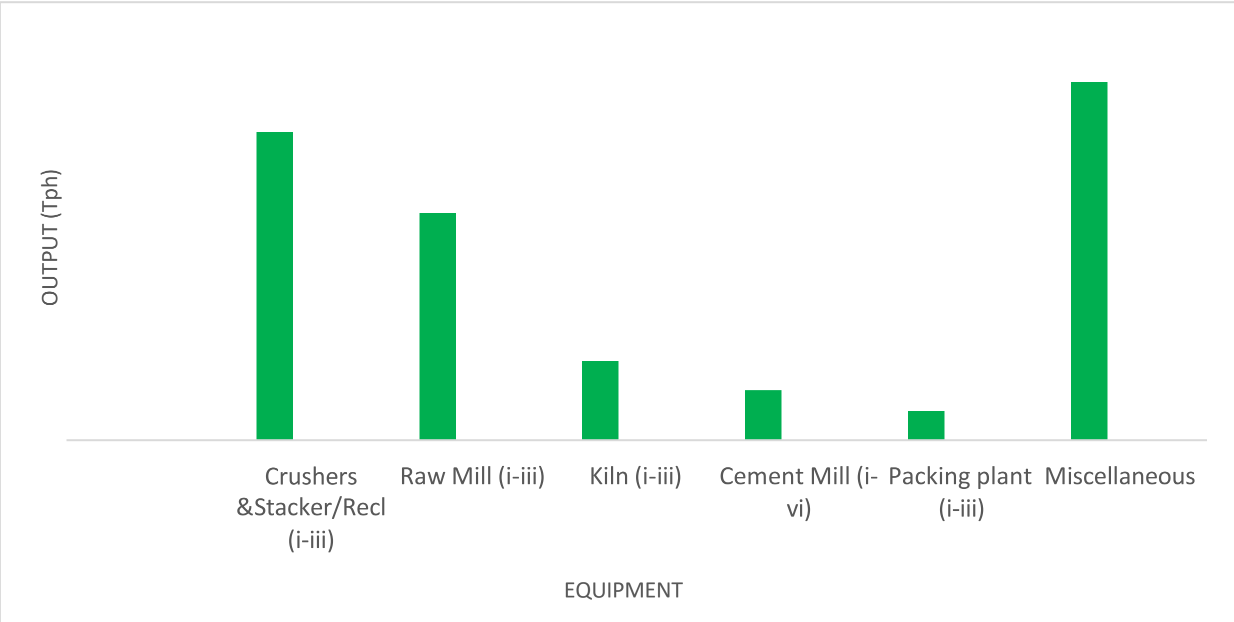

Figure 4.4 Output (Tph) versus Equipment in the plant

Form the graph in fig 4.4 the miscellaneous includes water pumps, compressors, canteens, clinic, staff quarters, vehicles, trucks, administrative offices, laboratory, control room, HVAC system etc. This has the highest output activities for the day to day smooth running of the cement plant.

The crusher and the raw mill is next in activities ensuring the raw material is available for the cement manufacturing process. All of these are energy intensive.

From the auditing assessment of the data collected, the following equipment are the most consuming electrical energy at Bua cement plant.

1. **The Cement mill and raw mill:** The largest electrical consumers.
2. **Fans and blowers:** Large fans and blowers are used throughout the process, including in the pre-heater, cyclones, kiln system, cooler, and for material transport and dust collection (e.g., baghouse fans).
3. **Conveyor systems:** The belts and motors that transport raw materials, intermediate products, and the final cement.
4. **Miscellaneous:** (Pumps for water and lubrication), compressors, HVAC systems etc.

Below is the summary of the electrical power received from the captive power plants: incomer 1, 2, 3, and 4, Jenbaker, Aggreko, and Warisila power generation, power consumed by the various sections of the plant, production, and saved power in the year 2024 are shown in Table 4.2

Table 4.2 Summary of annual Electric Power Received, Consumed and Production

	Power Received(Kwh)	Power consumed(Kwh)	Production (mt)	Power Saved(Kwh)
Total	**1,146,158,804**	**1,069,907,990**	**79,456,028**	**76,250,814**

From Table 4.2, Power supplied by captive power plants for 12months is 1,146,158, 804 kWh Power consumed by the entire factory is 1,069,907,990 kWh for a production output of 79,456,028 metric tons of the plant. Subtracting power received from power consumed by the plant, we have 76,250,814 kWh as power saved

4.2 The Electrical Energy Intensity

This measures the amount of electrical energy consumed per unit of economic output (GDP) or production. It is a key indicator for energy efficiency. Table 4.3 reflects the energy intensity of different section of the plant in kilowatt hour per ton of cement (kwh/ton cement) for one year.

Table 4.3 Electrical Energy Intensity of Various Section of the Plant.

Source of Data: Bua Cement Plant 2024

Operations	**Electrical Energy Intensity** (kWh/ton cement)
Crusher	2.45
Raw Material	16.49
Kiln	21.48
Cement mill	44.91
Packing plant	1.08
Miscellaneous	2.33

Ratio of conversion of material to one ton of clinker, i.e. Clinker factor =1.6. Energy intensity for additives production is negligible. Therefore, the Electrical Energy Intensity in different departments of the factory, using equation (3.10) is as following:

Energy Intensity in Crusher =**2.45** kWh/ton cement

Energy Intensity in Raw Material Mill = **16.49** kWh/ton cement

Energy Intensity in kiln = **21.48** kWh/ton cement

Energy Intensity in cement mill =**44.91**kWh/ton cement

Energy Intensity in packing = **1.08** kWh/ton cement

Energy Intensity for miscellaneous = **2.33** kWh

Using equation (3.10) the total Electrical Energy Intensity in cement plants is calculated based on summation of Electrical Energy Intensity in different sections of the factory which is

EEI (KWh/ton cement) = [2.45+16.49 + 21.48+44.91+1.08 +2.33]

= **88.74 kWh/ton cement**

Therefore the Electrical Energy Intensity (EEI) of the plant is 88.74 kWh/ton cement

The (annual) electrical energy intensity at Bau Cement plant for the year 2024 was evaluated as 88.74 kwh/ton cement, and comparing this value with the best cases in Iran and in the world which is 80 - 120 kWh/ton cement, (energyequipsys/ Vol 2/No2/AUG 2014/ 171-184 Morteza Gholipour Khajeh et al, 2014). Electricity accounts for about one third of the total cost of cement production. Which fall within bench mark indicate an efficient energy usage at the plant.

4.3 Direct, Indirect and Process Energy Requirement

Table 4.4 represent power consumed in kwh/t of the crushers/stackers/reclaimers section, rawmills, the kilns, cement mills, parking plants for all the three lines of the factory and other miscellaneous.

Table 4.4 Electrical Energy Analysis

S/NO	Equipment	Running hours (h)	Production(Mt)	Power consumption (kwh)
1	Crushers (1, II, &III) & ETS/Stacker/Recl. for line I,II&III)	18,704.41	16,901,640	41,332,457
2	Raw mill (I,II&III)	23,818.06	15,860,013	261,575,910
3	Kiln (I, II& III) (Clinker)	42,171	9,825,933	211,053,826
4	Cement Mill (I,II,III,IV,V & VI)	78,910	11,515,875	517,163,020
5	Parking plant I,II & III	186,043	16,149,562	17,364,106
6	Miscellaneous (cement)	8,760	9,203,005	21,418,671
	TOTAL	**358,406.47**	**79,456,028**	**1,069,907,990**

Using equation 3.1 to 3.5

To evaluate the Direct Electrical Energy Requirement (DEER)

Using equations 3.1 – 3.5 and the values in Table 4.4

DEER = $\frac{1069907990}{79456028}$=13.47 kWh/t

IEER = $\frac{21418671}{9203005}$= 2.33 kWh/t

PEER = 13.47 + 2.33 = 15.8 kWh/t

If the factory process energy required is **15.8 kWh/t** of cement and a ton is 20bags

Therefore, **0.79 kWh** is used to produce a bag of cement.

From the pie chat in figure 4.2, the packing plants for all the lines is the finished product delivery of the factory has a percentage running time of 53% follow by the cement mills of 23% while the kilns, raw mill and the crushers runs 12%,7% and 5% respectively. Running time is synonymous to energy consumption.

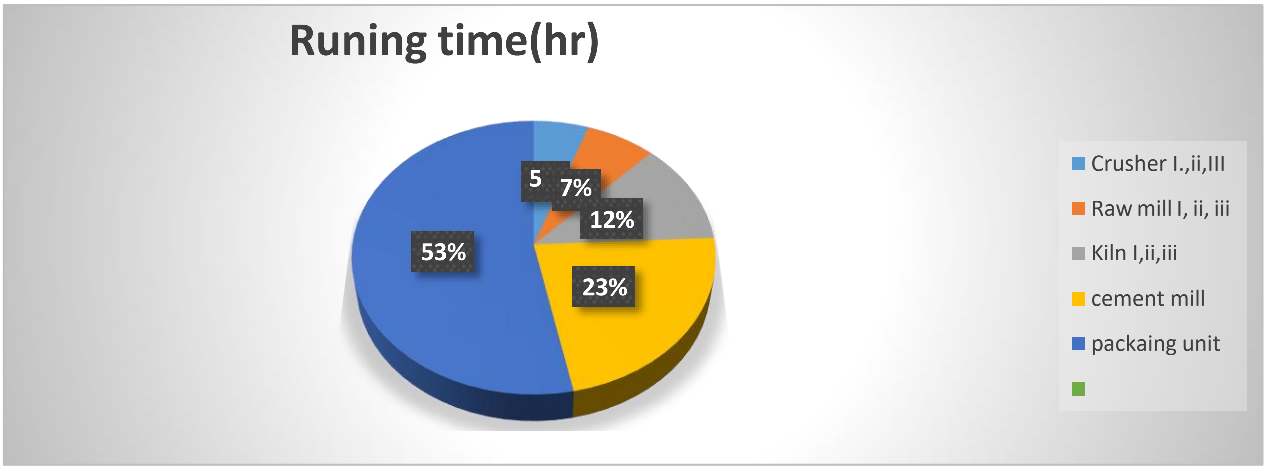

Fig 4.5 Pie Chat Energy Analysis in each sections.

Table 4.4 showed the electricity consumption per tons of cement produced in every stages. The analysis showed that the highest electrical energy consumer is the cement mill and the raw mill. The most power consuming parts of the kiln system are the induced draft gas fan motor(s), the cooler fan motors and the kiln drive motors.

It would be necessary to change more energy consuming equipment to lesser energy consuming ones. The power consumption of the induced draft (ID) gas fan(s) mainly depends on the total pressure drop in the kiln system. Most of this pressure drop occurs in the preheater. Increasing the preheater cyclone dimensions will reduce the pressure drop, but for any given preheater geometry, stable preheater operation (without raw meal falling through the riser ducts) requires a certain minimum pressure drop. The Low Pressure (LP) cyclone, a standard component in all kiln systems, was installed at the plant to ensure a low pressure drop in the preheater while maintaining high efficiency with small cyclone dimensions.(www.flsmidth.com)

4.3 Thermal Energy Consumption Audit:

The thermal energy consumption aspect of the audit is considering the pyro process, which is the formation of clinker in the kiln at 1450^{o}C through the cyclones, preheaters and further cooling of the clinker at the cooler to a temperature of 80 to 100 degree Celsius at exist.

The specific heat consumption of fuel at various kiln systems depends mainly on the kiln burner and the calciner burner, preheater stages, the cooler, the raw mix composition, and the fuel type. Table 4.5 show the gas consumption at the kiln burner and the calciner for all the lines for one year.

Table 4.5 Gas Consumption in the Kiln Burner and the Calciner Burner for Line 1, 2 & 3 of Bua cement plant.

	Line 1		Line 2		Line 3		Total. Energy Consumption
Month	Main Burner	Calciner Burner	Main Burner	Calciner Burner	Main Burner	Calciner Burner	Line1,2&3
Jan-Mar.	12998848	17559861	12735559	23963086			
Apr.-Jun	13285422	17462285	12792176	24477816	6314384	11449632	
Jul. -Sept.	11932224	16759167	11406921	22950876	9046705	16365843	
Oct.-Dec.	5859004	9982226	12502801	26153525	4372739	8483738	
SUB	44075498	61763539	49437457	97545303	19733828	36299213	
YEARLY TOTAL	105,839,037		146,982,760		56,033,041		**308,854,838NM^3**

For other fuel consumption; high product fuel oil (HPFO) and Lignite coal see appendix V for details.

Table 4.6 is fuel consumption miscellaneous for other usage in line 1 and 2, for line 3 there was shut down maintenance.

Table 4.6 Fuel Consumption (Miscellaneous) Year 2024 Bua cement plant

	Line 1 (MJ/Nm^3)	Line 2(MJ/Nm^3)	Total
March	680	720	**1400**
June	692	720	**1412**
September	690	726	**1416**
December	685	730	**1415**
Total			**5643MJ**

Table 4.5 & 4.6 reveals how much gas, high product fuel oil (HPFO) and coal was used in the main burner and the calciner burner in the pyro process of the kiln in the year 2024. These consumption covers the three lines of the factory for all the different type of fuel usage.

Therefore total summary of gas consumption for the three lines processes at the kiln is 308,854,838 Nm^3 Total High Product Fuel Oil (HPFO) used is 1,884,934.47 Nm^3

Total Lignite Coal consumption for line 3 is 28,683.00Nm^3

Total fuel (petrol) consumption Miscellaneous is 5643 MJ

Therefore Total Thermal Energy Consumed of the different fuel usage is multiply the volume by the calorific value of the different fuel given as indicated in equation (3.14).

[(308,854,838 x 37.3) + (1,884,934.47 x 43.5) + (26,683 x 29.3) + (5643 x 45)]=

$1.152028546 \times 10^{10} + 81994649.45 + 781811.9 + 253935 = 1.1603 \times 10^{10}$MJ

The total thermal energy consumption for the kilns per tons of clinker is **1.1603 x 10 ^{10}MJ/t of clinker**

4.3.1 Result of the Computation of the Calorific Value in MJ/m^3

The result of the computation of the calorific value at 25^{o}C and at constant pressure of the Natural Gas with gross calorific value (GCV) and lower calorific value (LCV) is shown in Table 4.7

Table 4.7 Result of the Computation of the Calorific Value in MJ/m^3 in Bua Cement plant

Constituents	GCV (MJ//Nm^3) (liquid)	LCV (MJ/Nm^3) (gaseous)
CH_4	0.03679	0.03315
C_2H_6	0.003359	0.003074
C_3H_8	0.000922	0.000849
C_4H_{10}	0.0002053	0.00019
Total	0.041281	0.037267

GCV =0.04128 MJ/m^3 at 25^{0}C **= 41.3MJ/Nm^3**

LCV = 0.037267 MJ/m^3 at 25^{0}C = **37.3MJ/Nm^3**

The heating values of Natural gas at Bua cement which is close to world accepted value of 42 and 37 KJ/ m^3 respectively from the data analysis. Please note this values varies from location to location as the heating value of natural gas in Hungary is 34.12MJ/m^3

The calorific value of the type of fuel used at Bua cement are indicated below base on calculation show above

Fuel Calorific Values

Gas **37.3MJ/ Nm^3**

Oil 43.5MJ/Nm^3

Coal 29.3MJ/Nm^3

Fuel (Diesel) 45MJ/kg

4.3.2 Heat Energy Intensity at the Kiln

From Table 4.4 total annual clinker production is 79456028 metric tons of clinker and the amount of heat produced at the three kilns is 1.1603 x 10 ^{10}MJ and using equation (3.11) the Heat Energy Intensity is been calculated as follows:

Thermal Energy Intensity (TEI)= $\frac{1.1603x10^{10}MJ}{78456028\ ton\ clinker}$ $= 147.89$ $\mathbf{MJ/t.cl = 0.2GJ/t\ clinker}$

The total thermal energy consumption for the kilns per kilogram of clinker is 147.89 MJ/t of clinker, or 0.2GJ/t comparing this with the global production of cement around (2.8-3.0)GJ/t of clinker respectively) shows an efficient energy saving potential of 2.6 to 3.1 GJ/t exist at Bua Cement Plant. The amount of heat (surface) energy gain can be utilized to optimize the plant effectiveness. Since the kiln and the calciner from the investigation are the major consumers of thermal energy in the cement plant.

.

4.3.3 Direct Thermal Energy Requirement (DTER)

Using equation 3.1 – 3.5 and the values in table 4.4

DTER = $\frac{1.1603x10^{10}}{9825933}$ =1.18 MJ/t

ITER = $\frac{21418671}{9203005}$ = 2.33MJ/t

PTER = 1.18 + 2.33 = 3.51 MJ/t or 0.00351GJ/t

The factory consumed 3.5 MJ/t or 0.004 GJ/t of cement and a ton is 20bags

It takes 0.2 MJ to produce one bag of cement.

4.4 Summary of Heat Loss at Various Sections

The summary of heat loss at various sections is tabulated in table 4.8 and some of the factors that causes the heat loss.

Table 4.8 Summary of Heat Loss at Various Sections

Clinker Production 9,825,933 TPH

Amb. Temp. 30^{o} C.

	Heat Loss (kcal/kg)		
	Radiation	**Convection**	**Total**
Kiln shell	3.6	3.9	7.5
Tertiary air	1.44	1.18	2.62
Preheaters (cyclones 1-5)	5.58	3.9	
Cooler	2.04	1.12	3.15
Riser	*8.92*	*4.47*	*13.39*
Total	**21.58**	**14.57**	**36.16**

From table 4.8

Total radiation and convection heat losses in MJ/kg

= 36.16kcal/kg = 151.29 kJ/kg = 0.15MJ/Kg

Total radiation and convection heat loss per unit area:

- 36.16/14.33 = 2.53kcal/m^2
- 151.25/14.33 = 10.56KJ/m^2 = 0.011MJ/m^2

4.4.1 Mechanism of Heat Loss

The extreme high internal temperatures of the kiln (1450°C) through the refractory lining to the steel kiln shell. The external shell then dissipates this heat by the following means.

I. **Conduction** through the refractory lining and steel shell.

II. **Convection and Radiation** from the outer surface of the shell to the ambient air.

III. **Forced Convection** (using water or air) at the riding rings (tires) is often used to manage specific temperature areas or to cool hot spots, creating a localized heat loss.

(Source: reseachgate.com)

4.4.2 Factors Affecting the Heat Loss at the kiln are

1. **Refractory condition**: The refractory lining insulates the shell and minimizes heat loss. Loss or degradation of the lining can lead to hot spots and increased heat loss.
2. **Shell surface temperature**: The amount of heat lost increases significantly with higher shell surface temperatures.
3. **Cooling method**: While general shell cooling is often done by ambient air and natural convection, specific cooling systems (like controlled water spray systems) are employed near riding rings to manage thermal expansion and mechanical stress, directly extracting heat from the shell to the cooling water.
4. **Kiln alignment**: Poor alignment can lead to mechanical stresses and potential shell damage, indirectly affecting thermal performance and leading to localized issues that may require targeted cooling. Heat loss through the kiln shell account for a notable portion of the total energy input around 10-15% via radiation and convection. While seemingly a loss, localized water cooling around riding rings is a necessary operational measure to prevent structural problems and manage mechanical stresses, ensuring the longevity and stable operation of the equipment. (Source: reseachgate.com)

4.4.3 Factors which Affected Convective Heat Loss at the kiln:

1. **Surface temperature**: Higher surface temperatures lead to greater heat loss.
2. **Air velocity**: Higher airflow over the surface increases the convective coefficient (h_c)
3. **Surface geometry and rotation**: The shape of the kiln and its rotation speed significantly influence the convective heat transfer.
4. **Insulation**: The effectiveness of the kiln's insulation plays a critical role in the surface temperature and, therefore, the heat loss.
5. **Air properties**: The thermal conductivity of the air, which is affected by its temperature and pressure, is also a factor in the calculation. (Source: reseachgate.com)

4.5 Composition of the Natural Gas

Table 4.9 shows the composition of the natural gas (obtained from the site and used to derive the mass, density and the molar gas constant for the natural gas using equation (3.22)

Table 4.9 Composition of Natural Gas (Roger et al 2004)

Constituents	**Symbol**	**M**	**Mole%**	**Mass kg**	**% mass**	**m_i/m**	**$R_i=R_0/m_i$**	**$m_i/m*R_i$**
Methane	CH_4	16	92.50	14.800	85.25	0.825	0.5197	0.443
Ethane	C_2H_6	30	4.82	1.4460	8.33	0.0833	0.2771	0.0231
Propane	C_3H_8	44	0.93	0.4092	2.36	0.0236	0.1890	0.0045
Butane	C_4H_{10}	58	0.16	0.0928	0.53	0.0053	0.1434	0.00076
Pentane	C_5H_{12}	20	72.17	0.1676	83.23	0.8323	0.4157	0.3460
Nitrogen	N_2	29	0.60	0.1680	0.97	0.0097	0.2969	0.00288
carbon dioxide	CO_2	44	1.01	0.4444	2.56	0.0256	0.1890	0.00484
hydrogen sulfide	H_2S	28	34.086	0.03408	94.1	0.941	0.2969	0.27934
Water vapour	H_2O	18	18.15	0.0180	16	0.16	0.4619	0.0739
Total	Total	287	224.426	17.58008	293.33			1.17832

$$\frac{101.325 \times 17.58008}{8.3144 \times 298\ k} = \frac{1.78130}{2.47769} = 718.936 / 1000 = \mathbf{0.7189 kg/m^3}$$

The composition of natural gas constituent is **0.7189 kg**/m^3, value is within the range generally accepted.

4.6 .Heat of Combustion of Natural Gas Constituents

Table 4.10 shows the heat of combustion of natural gas with the major constituent from which the values of the gross (or higher and net or lower) calorific values of the gas can be obtained by multiplying the percentage of each combustible component in the fuel by the known heat of combustion of the combustible components when in their gaseous states. Alternatively the heat of combustion is calculated from the difference between the heats of formation (ΔH_f^o) of the products and the reactants under standard conditions.

$$\Delta H_{comb}^o = \Delta H_f^o \text{ (products)} - \Delta H_f^o \text{ (reactants)} \quad \text{(chemistry learner)}$$

Table 4.10 Heat of Combustion of Natural Gas Constituents, - ΔH (MJ/m^3) at 25^{0}C and 101.560 kPa constant pressure)

Constituents	**H_2O (liquid) and CO_2 (gas)**	**H_2O(gas) and CO_2 (gas)**
CH_4	37.74	35.81
C_2H_6	69.62	63.72
C_3H_8	99.08	91.35
C_4H_{10}	128.47	118.65

(Source: Roger et al, 1994 ,Heat value of natural gas component by George Armstrong et al 1982)

4.6.1 Calculations of Neutral Combustion Gases and Combustion Air

The hydrocarbons in the natural gas were assumed to burn according to their stoichiometric reactions as follows:

$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$

$C_2H_6 + 3.5O_2 \longrightarrow 2CO_2 + 3H_2O$

$C_3H_8 + 5O_2 \longrightarrow 3CO_2 + 4H_2O$

$C_4H_{10} + 65O_2 \longrightarrow 4CO_2 + 5H_2O$

Sample calculation:

Amount of O_2 required for combustion is calculated from the above chemical equation as follows:

$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$

1Nm^3 of CH_4 requires 2Nm^3 of O_2

0.925 Nm^3 of CH4 will require 2 x 0.925Nm^3 of O_2

Neutral Combustion Air (NCA) required = $\frac{2 \times 0.925}{0.2095}$ = **8.831 Nm³**

Using the method above to evaluate the stoichiometric combustion of the natural gas for the kiln end gas and assuming 20.95% for the percent of oxygen in the air, neutral combustion air required for other component are calculated and tabulated as shown in the Table 4.11

Table 4.11 Stoichiometric Combustion of the Natural Gas

Natural Gas Component	**% Vol.**	**O_2 Required**	**Neutral Comb. Air (NCA)**	**Neutral Waste Gases (NWG)**		
				CO_2	N_2	H_2O
		(Nm^3)	(Nm^3)	(Nm^3)	(Nm^3)	(Nm^3)
CH_4	92.50	1.850	8.835	0.925	6.985	1.850
C_2H_6	4.82	0.1687	0.806	0.096	0.637	0.145
C_3H_8	0.93	0.0465	0.222	0.028	0.176	0.037
C_4H_{10}	0.16	0.0104	0.050	0.006	0.039	0.008
CO_2	1.01			0.010		
N_2	0.60				0.006	
Total	**100.02**	**2.0756**	**9.913**	**1.07**	**7.84**	**2.04**

4.6.2 Calculation of Waste Gases and Neutral Combustion Air

The amount of waste gases and neutral combustion air per kg gas were obtained by dividing the values obtained in Table 4.11 by the product of the density 0.775kg/m³ and the calorific value of gases (37.3 MJ/Nm³).

$$NCA = \frac{9.913}{37.3 \times 0.775} = 0.343 MJ/m^3$$

$$H_2O = \frac{2.04}{37.3 \times 0.775} = 0.071 MJ/m^3$$

$$CO_2 = \frac{1.07}{37.3 \times 0.775} = 0.037 MJ/m^3$$

$$N_2 = \frac{7.84}{37.3 \times 0.775} = 0.271 MJ/m^3$$

4.7 Air Balance

From Table 4.12 shows air measurement, dust load and temperature in the kiln and cooler of the Bua cement, kiln combustion operations for the three lines. Air balance is require for proper combustion

Table 4.12 Kiln and Cooler Exhausts Parameters

	Kiln 1	Cooler 1	Kiln 2	Cooler 2	Kiln 3	Cooler 3
Temp(^{O}C)	35	30	32	28	34	32
Dust Load (Nm^3/min)	36.7	37	32.6	26	12.3	28.4
Volume	730561.67	323533.05	579396.18	260728.28	623233.13	280454.91

Table 4.13 reveals cooler air volume, pressure and temperature been supplied by the draft fans 1 to 11 to bring the high temperature of the clinker to about 30-80 ^{O}C.

Table 4.13: Cooler Air Volume (Temp 30^{O}C)

	Fan 1	Fan 2	Fan 3	Fan 4	Fan 5	Fan 6	Fan 7	Fan 8	Fan 9	Fan 10	Fan 11	Kiln Feed (tph)
Cooler 1 (Nm^3/min)	**686**	**888**	**640**	**983**	**928**	**1189**	**1227**	**1208**	**1217**	**1076**	**1234**	**380**
Cooler 2 (m^3/hr)	**11527**	**14529**	**14034**	**41966**	**54375**	**56398**	**54672**	**70911**	**73348**	**70226**	**99999**	**320**
Cooler 3 (m^3/hr)	**16676**	**14570**	**14073**	**44605**	**58784**	**58453**	**50149**	**78222**	**70365**	**80314**	**76322**	**350**
Cooler 1 (mbar)	**88**	**58**	**57**	**53**	**47**	**48**	**47**	**44**	**42**	**41**	**32**	
Cooler2 (mbar)	**118.9**	**103.2**	**103.2**	**44.5**	**36.6**	**36.2**	**32.3**	**27.6**	**29.4**	**29.9**	**18.0**	
Cooler 3 (mbar)	**108**	**94**	**98**	**50**	**50**	**48**	**47**	**47**	**45**	**48**	**49**	
Cooler1(^{0}C)	**43.0**	**40.0**	**39.0**	**37**	**38**	**47**	**74**	**74**	**70**	**64**	**61**	
Cooler 2^{0}C)	**51.0**	**55.9**	**60.1**	**70.6**	**69.1**	**68.5**	**87.6**	**51.6**	**70.4**	**84.0**	**56.8**	
Cooler3(^{0}C)	**61.5**	**44.0**	**66.0**	**79.8**	**77.5**	**80.1**	**82.6**	**85.1**	**70.0**	**80.7**	**79.5**	

4.7.1 Parameters of Air Balance at the kiln

Refractory lining of 200mm is put into consideration:

The Primary air flow in the kiln is 9,583m^3/hr from the burner pipe.

Velocity of the primary air = 28.1m/s

Secondary air flow = 418,959 m^3/hr

Velocity of secondary air = 8m/s

Tartary air flow = 650,377m^3/hr

Velocity of tartary air = 26.6mls

Preheater exhaust air = 865,952 m^3/hr

Velocity of preheater exhaust air = 15.1m/s

Cooler exhaust air = 499,329 m^3/hr

Velocity of cooler exhaust air = 13.1m/s

4.8 Kiln Heat Balance

For heat balance to occur at the kiln, heat input must be equal to heat output. Data taking from the CCR of Bua cement plant.

4.8.1 Parameters of the Kiln Heat Balance (Input and Output)

From Appendix II Heat Balance at the Kiln

Total Heat Input (kcal/kg Clinker) =797

Total Heat Input (kJ/kg Clinker) = 3333

Total Heat Input (kJ/s Clinker) = 191463

Heat Output (kcal/kg Clinker) = 799

Total Heat Output (kJ/kg Clinker) = 3342

Total Heat Output (kJ/s Clinker) =191976

4.8.2 Heat balance losses

Heat losses (kcal/kg Clinker) =2

Heat losses (kJ/kg Clinker) = 9

Heat losses (kJ/s Clinker) = 523

Therefore firing according to fuel mass is **770.6 kcal/kg cl** and firing according to heat balance error **778.7kcal/kg cl.** Thus % error = **0.27**

4.9 Cooler Heat Balance (Input and output)

At Reference Temperature of 25^{o}c

Total Heat Input (kcal/kg Clinker) =410

Total Heat Input (kJ/kg Clinker) = 1716

Total Heat Input (kJ/s Clinker) = 98549

At Reference Temperature of 29^{o}c

Total Heat Input (kcal/kg Clinker) =407

Total Heat Input (kJ/kg Clinker) = 1701

Total Heat Input (kJ/s Clinker) = 97731

At Reference Temperature of 25^{o}c

Total Heat Output (kcal/kg Clinker) = 412

Total Heat Output (kJ/kg Clinker) = 1724

Total Heat Output (kJ/s Clinker) =99012

At Reference Temperature of 29^{o}c

Total Heat Output (kcal/kg Clinker) = 409

Total Heat Output (kJ/kg Clinker) = 1709

Total Heat Output (kJ/s Clinker) = 98194

Cooler Heat balance losses at 25^{o}c

Heat losses (kcal/kg Clinker) = 2

Heat losses (kJ/kg Clinker) = 8

Heat losses (kJ/s Clinker) = 463

Cooler Heat balance losses at 29^{o}c

Heat losses (kcal/kg Clinker) = 2

Heat losses (kJ/kg Clinker) = 8

Heat losses (kJ/s Clinker) = 463

Thus % error =**0.47**

However, the Energy Audit studies showed for a recovering of energy for a dry type cement rotary kiln system with a capacity of 6000 tons of clinker per day of 15.6% of the total energy input could be recovered by optimizing the energy recovery and the clinker cooler efficiency**.** Therefore the efficiency of the clinker cooler is the heat recovered from the hot clinker and subsequent preheating of the air used for calcination. The recovered heat and the preheated air are known as the secondary air in the rotary kiln and tertiary air at the calciner.(The unrecovered heat that leaves with the clinker out of the cooler represent the actual heat loss of the system)

4.10 Performance Efficiencies, Utility and Reliability Factors

New equipment and systems, turnover of personnel, retrofits, and temporary repairs associated with cement plant has become semi-permanent. All of these situations and others are the possible causes of eroded production efficiency.

4.10.1 Performance efficiency of equipment and personnel

In order to evaluate performance efficiency, utility and reliability factor, the following measure were employed.

Performance efficiency of the Crusher= $\frac{\text{production}}{\text{Expected production rate}}$

= $\frac{16901640}{6000}$= 2,816.9 =28.2%

-Percentage efficiency of the Raw mill= $\frac{15860013}{6000} = 2{,}643.3$ = 26.4%

- Percentage efficiency of the Cement mill = $\frac{11515875}{6000} = 1{,}919.3 = 19.2\%$

- Percentage efficiency of the Kiln = $\frac{9825933}{6000} = 1{,}637.7$ =16.4%

- Percentage efficiency of the packaging unit -$\frac{16149562}{6000} = 2{,}691.6 = 26.9\%$

4.10.2 Utility Factor of Equipment.

Utility factor of the Crusher= $\frac{running\ time}{total\ time\ available}$= $\frac{18704.41}{8760}$ = 2.1

Where total time available is 24hr =1day.Therefore 24x365days=8760hrs

Utility factor of the raw mill =$\frac{23818.06}{8760} = 2.7$

Utility factor of the Cement mill =$\frac{78910}{8760} = 9.0$

Utility factor of the Kiln =$\frac{42171}{8760}$= 4.8

Utility factor of the Packaging unit =$\frac{186043}{8760} = 21.2$

4.10.3 Reliability Factor of Equipment in the various section of the plant

Reliability Factor = $\frac{Running\ time}{Incident\ time+Running\ time}$

Relability Factor for Crusher=$\frac{18704.41}{358406.47} = 0.05$

Relability Factor for Raw mill=$\frac{23818.06}{358406.47} = 0.07$

Relability Factor for Cement mill=$\frac{78910}{358406.47} = 0.22$

Relability Factor for Kiln =$\frac{42171}{358406.47} = 0.12$

Relability Factor for packaging plant =$\frac{186043}{358406.47} = 0.52$

Table 4.14 Performance Efficiencies, Utility and Reliability Factors of the Bua cement plant

The measures above is tabulated below on table 4.14. It represent how efficient the equipment/personnel performance were as a result of its utility factor and how reliable they were in terms of energy utilization.

Equipment	Performance Efficiency (%)	Utility Factor (%)	Reliability Factor (%)
Crusher	28.2	2.1	0.05
Raw mill	26.4	2.7	0.07
Cement mill	19.2	9	0.22
Kiln	16.4	4.8	0.12
Packaging plant	26.9	21.2	0.52

Fig 4.6 line chat of the Performance efficiency,utility,and reliability factor of Bua cement plant

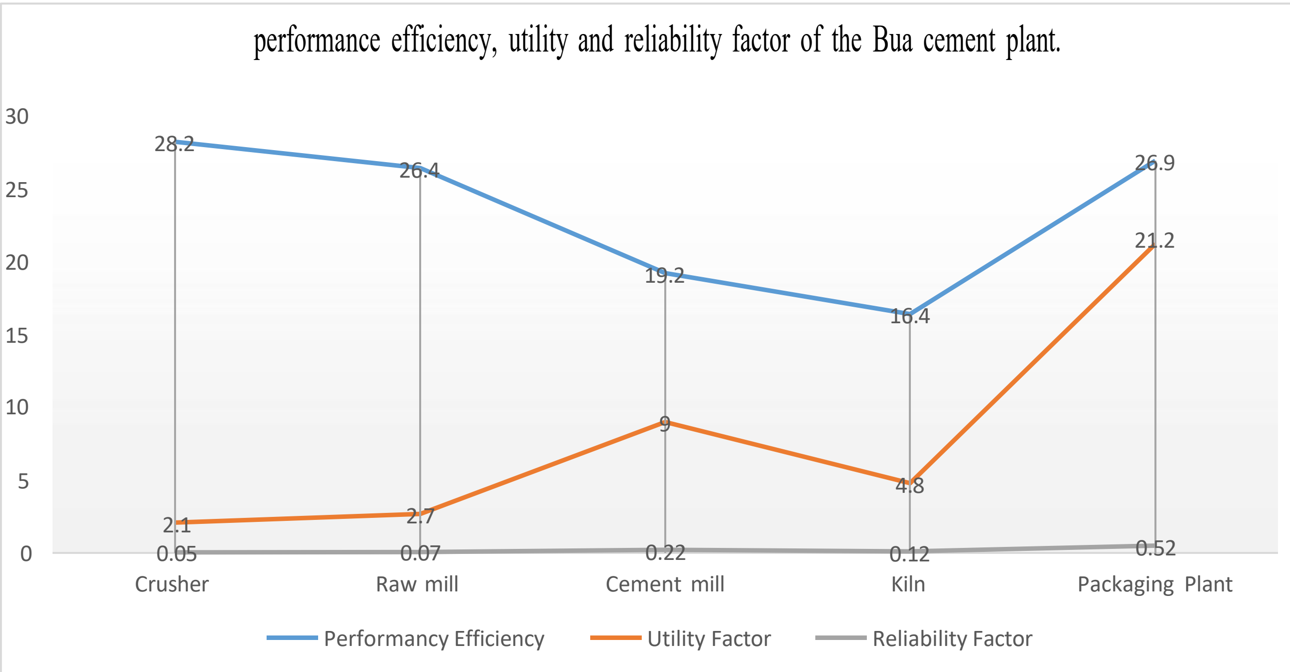

Figure 4.6 show a clear indication of the performance efficiency, utility and reliability factor of the Bua cement plant. This shows the performance index of the plant how equipment/ personnel performance in terms of energy utilization. It is however recommended that kiln Load Study be performed to model the stresses in the kiln shell, rollers and shafts, and riding rings that result from loading characteristic that may occur based on changes in operating conditions and equipment modifications. Kiln Load Study program can help to understand the root cause of the

symptoms, and in depth analysis can provide repair solution to minimize unscheduled shutdowns. In addition, the power draw of the kiln, as it relates to these changes, may also be predicted

The calculations may be repeated for several different load conditions in order to evaluate whether component modifications will be required to support additional stresses for a given situation.

Process Audit is also recommended as the objective of audit programs is to review the process from beginning to end. The process, mechanical, and control specialists can help identify the bottlenecks and deficiencies that are costing money. By evaluating the process through review of records, state of the art analytical tools like condition monitoring locally or online, where accessible, employee interviews, laboratory analysis and observation will help to optimize the performance of plant equipment.

4.11 Discussion on Energy Audit result obtained and findings on Bua cement plant

Heat energy intensity is 0.2GJ/t clinker With Global production around 3.0 – 3.6GJ/t having heat gain of 2.8 – 3.4 GJ/t. The amount of heat (surface) energy losses can be utilized to optimize the plant effectiveness, which should be quantified with respect to heat and power consumption as well as the resultant production level. However there are kiln heat balance % error of 0.27 and cooler heat balance % error of 0.47. Below are listed some of the innovative ideas that can be employed to minimized if not eliminate these % errors: The study concludes that significant efficiencies exist in the kiln and grinding sections. However, the Energy Audit studies showed for a recovering of energy for a dry type cement rotary kiln system with a capacity of 6000 tons of clinker per day of 15.6% of the total energy input heading for waste could be recovered by optimizing the energy recovery and the clinker cooler efficiency**.** Therefore the efficiency of the clinker cooler is the heat recovered from the hot clinker and subsequent preheating of the air used for calcination. The recovered heat and the preheated air are known as the secondary air in the rotary kiln and tertiary air at the calciner. The unrecovered heat that leaves with the clinker out of the cooler represent the actual heat loss of the system.

4.11.1 Kiln Seals

Replacement of kiln seals can lead to a large reduction of entrance of false air. It is well known that the flow of false air entering is always highest where the temperature in the system is highest. At both ends of the dry rotary kiln the temperature is more than 1200^{o}C. An increase in the false air intake of 0.1kg air/kg clinker will cost 75.35kJ/kg – 83.72kJ/kg clinker (18-20kcal/kg clinker) for any kiln system.

4.11.2 Refractories

High efficiency refractories: Modern preheater designs tend to increase the number of cyclone stages as well as incorporate tertiary air ducts and calciners, so radiation from the surface area of the stationary equipment becomes an important factor; the use of both highly efficient and light refractoriness is therefore important, although the investment costs should always be compared with the potential savings.

4.11.3 Minor Equipment Exchange

This involves the exchange of various minor equipment:

1 *Modification of existing cyclone outlet to a model of steeper outlet;*

Improve the material flow ability out of the cyclone, it has been proven to be particularly successful in cyclones where the temperature is 700ºC or above for 4-stage preheaters. These outlets are standard outlet for 5 and 6 stages preheater.

2 *Installation of flap gates (single or double);*

Reduces the amount of the by-passing hot air and stabilizes the flow of materials in the pipes.

3 *Installation of spreader boxes and plates*

It improves the dispersion of materials into riser pipes. These specially designed boxes placed at the lowest possible points in the kiln smoke chamber/riser duct have proven very efficient in keeping the smoke chamber and riser duct clean without much risk of the formation coating.

4.11.4 Calciner Modification

This relates to the process of decarburization of calcium carbonate which takes place mostly in the calciner vessel. The combustion of fuel also takes place here but it is dependent on retention time which suggests that the size of the calciner is more critical with respect to combustion than calcinations. By enlarging calciners, complete combustion of fuel can be achieved.

4.11.5 Addition of Cyclone Stages

By increasing the number of cyclone stages the heat transfer of the preheater will be improved; typically some 41.86 – 62.79kJ/kg (10 - 15kcal/kg) clinker can be saved. When adding further stages studies of the tower foundations are essential to confirm the extra weight and height that can be supported.

4.11.6 Firing in Riser Types

The purpose of this upgrade is to burn the fuel with the lowest amount of overall excess air and thereby reduce heat consumption. Excess air from the kiln as well as the false air entering the kiln inlet seal will partly be consumed as combustion air. Another purpose of firing in the riser pipe is to reduce the burning zone load so that the evaporation of volatiles as Sulphur, alkaline and chlorides will be for the two lower most cyclone stages. Most cases indicate that it would be an advantage to enlarge the diameter of the riser pipe above the smoke chamber to allow for further retention time.

4.11.7 Co-Generation Process for Clinker and Electricity

For sustainable development, triple bottom lines of economic prosperity, social equity and environmental quality are to be met. Cement industry is highly energy intensive. Pyro processing consumes about 80% of the total energy requirement.

Environment quality can be assured by environmental protection and one of the methodology by which environment can be protected is by effecting the reduction in the present energy consumption. This can be achieved by re-engineering the clinker manufacturing process. For example by passing pre-heater in clinkering process so that the waste heat of the kiln exit gases can be used for generating electrical power to the tune of 150-190kWh/t clinker. Surplus power can thus be made available under social equity to local inhabitants for lighting, provision of potable water for drinking, school, hospital and agro-based industries.

In dry process cement clinker production line, the heat of the exhaust gases from the clinker burning system has to be used efficiently by heat exchange with the raw materials fed to avoid heat loss. A new co-generation process using Circulating Fluidized Bed (CFB) technology in China is combined with the cement clinker calcining process. With this process, the temperature of the exit gas is low as 200^{o}C, so that heat efficiency of the clinker burning process is improved. A new co-generating process for cement and electricity with a circulating fluidized bed (CFB) apparatus was developed and applied to upgrade a kiln line at the Huhehaote cement plant in inner Magnolia of China. To expand the outputs of cement as well as electricity of kiln line, a circulating fluidized bed (CFB) apparatus should be installed between the boiler and the rotary kiln replacing the gravitational dust setting chamber. Cold cement raw meal is fed into CFB riser and pre-heater and pre-calcined before it is charged into the cement rotary kiln. The CFB apparatus is operated at adjustment temperatures of 800^{o}C to 1200^{o}C. The degree of decomposition of calcium carbonate ($CaCO_3$) of cement raw meal are controlled above 85% before it leaves the CFB apparatus, so that the specific clinker capacity of the rotary kiln is increased to twice that before upgrade . In this case the CFB calciner and the waste heat boiler replace the cyclones suspension pre-heater and precalcining system. The hot waste gases of 800^{o}C to 1200^{o}C from the CFB apparatus are high quality heat energy source for the boiler which is located downstream of the

CFB cyclone. Because the gas mass flow can be controlled by the CFB furnace according to the requirement of the boiler, the electric power station is able to generate more electricity at a certain clinker output to meet the requirement of the overall cement plant.

Kiln should be fed from burner side, so that the high grade energy in upper portion of the kiln flame which is hitherto being carried out either by kiln exit gases or getting lost through radiation from the kiln shell is instead used in rapidly heating of the feed so that the kinetics of reactions are accelerated in burning zone to improve clinker quality and to reduce energy consumption.

Kiln flame can be enriched by oxygen to increase productivity through better coating, better clinker quality, improved lining life, reduced kiln surface heat loss and lesser percentage of dust in kiln exit gases.

Further by installing tumbler lining in kiln, clinker quality can be improved and energy consumption can be reduced. Also cement plants can go for geo-thermal power plants, wherever feasible to meet their energy requirement as this conserves fossil fuels and provides clean safe renewable and sustainable energy using little land

4.11.8 Using High Efficiency Crusher (HIC) as a Pre-Grinder before the Cement Mill

The cement mills are generally Ball Mills which could be either open-circuit or closed circuit mill. The Ball Mill is not energy efficient in the coarse size reduction. Installing a Roll press or a Horizontal Impact Crusher (HIC) having a capacity of 300tph (including recirculation) to act as a pre-grinding and perform the initial size reduction before the mill.

Impact Crusher as a pre-grinder before the mill for the initial size reduction would increase the capacity and reduce the specific energy consumption. The HIC have a three deck-vibrating screen to separate and return the coarse material back to the HIC by gravity while the fines are conveyed to the hopper through a belt conveyor. The fines from the hopper can later be fed to the mill through a belt conveyor. Thus, the HIC and the mill are made independent so that the operation of one does not affect the other.

is to suspend the kiln concentrically inside the tyre. In this way the load is absorbed tangentially to the kiln shell and the shell is free to expand radically.

Double- lamella Seals:- the kiln inlet and outlet seals allow a high degree of wobble at the kiln ends. The double lamella seals require no greasing and are practically maintenance free.

4.11.9 Recycling Process

Recent reports show that more cement manufacturers have become interested in generating electricity from that of the waste gas. Some cement plants are able to generate almost all their total power requirements by the utilization of waste heat directly from long dry rotary kilns off-gases, so that the cost of cement production could be decreased.

Recycling is the process of transforming materials that would otherwise be discarded as waste, into useful commodities; this recycled material may be either the raw material or the final product. Recycling the waste materials into reusable products has multi-fold benefits. Some of the benefits of recycling process are:

1. Conservation of energy
2. Conservation of material resources
3. Energy consumption for the manufacturing process itself and competitiveness.
4. Energy consumption for the transportation of material to manufacturing site

Recycling of waste products reduces the usage of virgin raw materials, which in turn conserves natural resources. Use of fly ash from thermal power station for manufacturing blended Portland cement would be example of recycling.

Typically, in cement industry manufacturing 100 million tons of ordinary Portland cement requires 140 million tons of limestone, if fly ash is used along with limestone quantity of limestone is saved.

1. Conservation of Energy

Energy conservation is a major benefit of recycling. Energy conservation by recycling manifests itself in two forms.

i. Substituting the recycled products for fresh raw materials eliminates energy consumption in transporting raw material to the manufacturing unit.

ii. The recycled materials will have undergone several stages of production. By recycling, the energy consumption required for the stage the material is taken for recycling is eliminated.

2. Competitiveness

Reduction in cost of raw materials and savings in energy input costs reduce the overall cost of the product and increase the competitiveness of industry.

4.11.10 Alternative Fuel and Raw Materials

Many industrial by-products and other waste materials can be recovered and used in cement manufacture. Some are incorporated into cement; others provide fuel needed to convert limestone into cement. Some of the materials are being used by companies around the world and not all of them are used in every country. Some are actively encouraged in some countries, but prohibited in others. For example, used tires are routinely burned as fuel in cement plants in Japan, France and Germany. But this practice is controversial in several other countries.

Bua Cement plant needs to develop a technology that will make use of waste as a fuel in cement kilns. This alternative fuel process has several benefits. It conserves fossil fuel such as gas or oil. It saves companies the chores of disposing of some of their own waste, and it removes waste from the environment, with no leftover material such as ash, which is often the case with other technologies. The process also contributes to the reduction of carbon dioxide, sulfur, and nitrogen oxide emissions. The use of these waste products in cement kilns avoids emissions that would be generated through incineration. Since 1997, the use of industrial waste as an alternative fuel in cement kilns in Argentina has saved 49,350m^3 of fossil fuels, and a total of 122,500 tons of industrial waste has been saved from landfill.

Table 4.15 Summary of Energy Audit in Bua cement manufacturing process

Table 4.15 Summaries the Energy Audit analysis of the manufacturing process of Bua Cement plant.

Process	Crushers (1, II, &III) & ETS/Stacker/Recl. for line I,II&III) Raw mill, Kiln, Parking plant (I,II&III),Cement mill (I,II,III,IV,V & VI), Miscellaneous (cement)
Electric power received (kwh)	1,146,158,804
Running hours (h)	358,406.47
Production (Mt)	79,456,028
Electric Power consumption (kwh)	1,069,907,990
Thermal power consumption (MJ/t)	1.16x10^{10}
Direct Electrical Energy Requirement (DEER) (KWh/t)	13.47
Indirect Energy Requirement (IEER)(KWh/t)	2.33
Process Electrical Energy Requirement (PEER)(KWh/t)	15.8
Direct Thermal Energy Requirement (DTER) (GJ/t)	0.00118
Indirect Thermal Energy Requirement (ITER) (GJ/t)	0.00233
Process Thermal Energy Requirement (PTER)(GJ/t)	0.00351
Electrical Energy Intensity(KWh/t)	88.74
Thermal Energy Intensity (GJ/t)	0.2
Electrical Energy losses (MWh/m^2)	2.93 x 10^{-6}
Thermal Energy Losses (kcal/m^2)	2.53
Electrical Power Gain or Saved (KWh)	76,250,814

From Table 4.9 the composition of our natural gas constituent use at Bua cement plant is 0.7189 kg/m^3 value is within the range generally accepted worldwide. And is simply the best base on combustion. Also from Table 4.15 the Electrical Energy Intensity 88.74 KWh/t fall within bench mark of 80 – 120 KWh/t of cement and the Thermal Energy Intensity is 0.2 GJ/t shows an efficient energy saving potential of 2.6 to 3.1 GJ/t exist at Bua Cement Plant. The amount of heat (surface) energy gain can be utilized to optimize the plant effectiveness.

If the plant process energy required is 15.8 kWh/t of cement and a ton is 20bags

Therefore, 0.79 kWh is used to produce a bag of cement. While the thermal process energy Requirement of the plant is 0.004 GJ/t of cement.

The electrical power consumed of 1,069,907,990 kWh from a total of power supplied from the captive power plants of about 1,146,158,804kwh for a total production 79,456,028 metric tons of cement for a running hours of 358,406.47hrs was able to save electrical power 76,250,814 KWh. This shows the effectiveness of the energy performance efficiency of the Bua Cement plant with a viable utility and reliability factor.

Therefore looking at the economic evaluation of these energy utilization and gain in 4.13

4.12 Economic Evaluation of Energy Consumption Cost

Using equation 3.24 electrical energy cost per kWh for production at the various sections of the plant using table 4.4.Total cost of electrical power consumption per annual for running the plant for 358,405.47 hours for a production of 79456028 metric tons using 1,069,907,990 kWh/ton in the year 2024 when a kWh of power was ₦225 is **₦ 24,072,929,780.00**

The total gas consumption for the three lines processes at the kiln per annual in year 2024 was 1.152 x 10^{10} MJ and the cost of gas from the Nigeria Midstream and Downstream Petroleum Regulatory Authority (NMDPRA) gave the price of natural gas for commercial users as $2.92 MMBTU in 2024. Converting 1.152x 10^{10}MJ to MMBTU is 10,920,960MMBTU

Average exchange rate in 2024 ₦1,472.15k to a dollar, therefore $2.92 = ₦ 4,298.68k

10,920,960MMBTU x ₦ 4,298.68k = **₦ 46,945,712,330.00**

The Total High Pour Fuel Oil (HPFO) used is 81,994,649.45 MJ, and the cost for a commercial user per fuel oil equivalent was ₦550. Therefore, 81,994,649.45 x 550 = **₦ 45,097,057,198.00**

Total Lignite Coal consumption for line 3 is =781,811.9 MJ x ₦ 191,379.50k per ton

= **₦149,622,770,500.00**

Total diesel fuel consumption Miscellaneous is 253,935 MJ, and the cost of it per liter in year 2024 is ₦1462.98k. Hence total cost is **₦ 8,255,596.14 k**

Electrical power gain is 76,250,814 kWh x ₦225 =**₦ 17,156.433.150.00**

Total Thermal energy consumed is1.16023x10^{10}MJ and the cost for it is **₦ 242,037,041,854.30**

4.13 Estimated Energy Usage and Cost, Bua Cement Plant

All type of energy usage in the process of production of cement were calculated and tabulated as showed on table 4.16. For a production of ninety-six million, five hundred and twenty-three thousand, nine hundred and forty metric tons (96,523940mt) in 2024, for total energy consumption for both thermal and electrical two hundred and sixty-eight billion, six hundred and six million eight hundred and seven -one thousand, seven hundred and six naira thirty kobo (₦268,606,871,706.30k) was spent on energy for the entire process of the cement production of Bua cement plant and electrical power gain or saved was ₦17,156,433,150.00. for the electric energy consumption this amount was spend ₦24,072,929,780.00 on 1,069,907,990 kwh and the thermal energy consumption, this was spent ₦244,533,941,926.30 on 1.16023x10^{10}MJ of natural gas, high product fuel oil (HPFO),Lignite coal and diesel.

Table 4.16 Estimated Energy Usage and Cost, Bua Cement Plant

Type of	**Price of Energy (₦)**	**Energy consumed**	**Energy Cost (₦)**	**Energy Gain**
Electrical power	225	1,069,907,990 kWh/t	24,072,929,780.00	17,156,433,150.00
Natural Gas	4,298.68	1.152 x 10^{10}MJ	49,520,793,600.00	
HPFO	550	81,994,649.45 MJ	45,097,057,200.00	
Lignite coal	191,279.50	781,811.9 MJ	149,544,589,300.00	
Fuel diesel	1462.98	253,935MJ	371,501,826.3	
TOTAL			**268,606,871,706.30**	**17,156,433,150.00**

4.14 Economic Model for Energy Conservation in Cement Processes

it was assumed that total investment can be done only by the factory; in this case, the feasibility study for each measure would be evaluated based upon cost benefit and analysis.

C = Cost of investment for energy saving measure

B = Effect of the measure (value of energy saved by the measure)

If B is greater than C (B>C) then, the measure are evaluated as economically feasible.

Besides, the payback period for each measure is divided into two “short term” and Long term” measure normally factories are not interested in the measures with long payback period at the moment due to high energy cost for the factories and also high risk in these kinds of investment because of the high investment cost. Therefore, the measures with short payback period and low cost has more priority from factory point of view at the moment.

Effective parameters for factory decision-making in this case are as follows:

- Cost of investment
- Reduction of energy costs
- Production increase
- Improvement in the quality.

In economic evaluation, in case energy saving measures is not economically feasible or they have long payback period, the financial assistance or the partnership of the government in another scenario also should be considered. From government point of view, the targets of energy conservation measure are considered based upon other priorities as follows:

- Energy saving
- Policy to reduce the energy supply
- Reduction of greenhouse gases and air pollutants
- Improvement of the national economy in the country for the future

In case the energy saving measures with both government and factory investment (national point of view) is not feasible, it is clear that the project will not be implemented.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study examined the energy use at BUA Cement Plant, Obu-Okpella, with the aim of understanding how energy is consumed across the production process and where improvements can be made. The work focused on both electrical and thermal energy, covering key stages such as raw material preparation, clinker production, cement grinding and packaging of the finished product. By doing this, the study was able to give a clear picture of how energy is used in the plant and where inefficiencies exist.

In Chapter One, the study introduced the problem by explaining how energy consumption plays a major role in cement production and how rising energy costs can affect overall performance. The objectives of the study were clearly stated, with emphasis on the need for an energy audit. Chapter Two reviewed existing studies and industry practices, pointing out that there is limited detailed analysis of energy performance in Nigerian cement plants. Chapter Three explained the methods used to collect and analyze data, while Chapter Four presented the results, showing how energy is consumed, how much it costs, and where losses occur.

From the findings, the plant recorded a total production of 96,523,940 metric tons in 2024**,** with a total energy cost of about ₦268.61 billion**.** Out of this, electrical energy accounted for 1,069,907,990 kWh, costing about ₦24.07 billion, while thermal energy took a much larger share, costing about ₦244.53 billion. The study also identified an electrical energy saving of about ₦17.16 billion, which shows that there are already some improvements in place, but more can still be achieved.

The results further showed that the cement mill and raw mill use the highest amount of electrical energy, while the kiln and calciner are responsible for most of the thermal energy consumption**.** However, the electrical energy intensity values was within the benchmark of global standards. The electrical energy intensity was 88.74 kWh/ton cement**,** which falls within the recommended range of 80–120 kWh per ton cement. The total thermal energy consumption for the kilns per of ton of clinker is 147.89 MJ/t of clinker, or 0.2GJ/t comparing this with the global production of cement around (2.8-3.0)GJ/t of clinker respectively) shows an efficient energy saving potential of 2.6 to 3.1 GJ/t exist at Bua Cement Plant. The amount of heat (surface) energy gain can be utilized to optimize the plant effectiveness

The study also found that a large amount of energy is lost during and after production of clinker, especially from the kiln in the form of heat and the uncooled clinker from the cooler. Other areas of loss include inefficient equipment and supporting systems like fans and compressors. These losses show that there is a strong opportunity for improvement, especially through better equipment performance, improved process control, and heat recovery systems.

In general, the study shows that while the plant is performing well in terms of production, its energy use is not as efficient as it should be. However, the good part is that there is a lot of room for improvement. With the right measures in place, such as better energy management practices and the use of more efficient technologies, the plant can reduce its energy consumption, cut down costs, and improve overall performance. This confirms that carrying out regular energy audits is very important for identifying problems and guiding improvements in industrial operations.

5.2 Recommendations

The recommendations presented are aimed at addressing identified energy inefficiencies and improving general plant performance through practical and sustainable measures. These includes;

i. The plant should ensure that all major energy-consuming equipment such as the kiln, cement mill, and raw mill operate at optimal efficiency through regular maintenance, proper calibration, and timely upgrades based on operational requirements.
ii. There is a need to strengthen operational control across all production units to ensure efficient utilization of both electrical and thermal energy, particularly in high-energy-demand areas such as the kiln, calciner, and grinding sections.
iii. A structured energy management system should be implemented to support continuous monitoring, evaluation, and control of energy consumption patterns, enabling data-driven decision-making and improved efficiency.
iv. Efforts should be made to reduce high specific energy consumption by adopting energy-efficient technologies, improving process integration, and benchmarking operations against international best practices.

v. Heat losses, especially from the kiln shell, should be minimized through the use of improved insulating refractories such as Lytherm and the adoption of waste heat recovery systems to harness otherwise lost energy.

vi. The plant should adopt sustainable improvement strategies, including effective utilization of waste materials, continuous staff training on energy efficiency practices, and ongoing research into innovative products such as eco-cement to enhance productivity and reduce operational costs.

REFERENCES

Adejumo, A. L., Akinlabi, S. A., Madushele, N., and Olatunji, O. O. (2019). Energy utilization, efficiency, and sustainability in the Nigerian cement industry. *Energy Reports, 5*, 162–170. https://doi.org/10.1016/j.egyr.2019.01.002

Aghbashlo, M., Hosseini, S. S., Tabatabaei, M., and Shahbeik, H. (2019). Exergy analysis of cement production systems: A critical review. *Renewable and Sustainable Energy Reviews, 99*, 112–128. https://doi.org/10.1016/j.rser.2018.10.012

Aghbashlo, M., Tabatabaei, M., Soltanian, S., Ghanavati, H., and Dadak, A. (2019). Comprehensive exergy analysis of a cement plant: A case study. *Energy*, 176, 102–115. https://doi.org/10.1016/j.energy.2019.03.162

Akinwale, Y. O.,and Aladejare, S. A. (2022). Private sector investment and industrial development in Nigeria: Evidence from cement manufacturing. *Journal of African Business*, 23(2), 256–273. https://doi.org/10.1080/15228916.2021.1942539

Akkaya, A. V., and Demir, A. (2017). Energy efficiency analysis of cement production: A case study. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 39*(10), 1021–1029. https://doi.org/10.1080/15567036.2016.1273374

Anantharaman, N. (2015). Energy efficiency improvement opportunities in cement plants. *International Journal of Engineering Research and Applications*, 5(5), 44–51.

Anoune, K., Bouya, M., Astito, A., and Abdellah, A. B. (2023). Energy audit methodologies and tools for industrial energy efficiency improvement. *Energy Reports, 9*, 1736–1749. https://doi.org/10.1016/j.egyr.2023.01.098

Aranda Usón, A., Capilla, A. V., and Ferreira, G. (2020). Energy efficiency and fuel substitution strategies in cement manufacturing. *Journal of Cleaner Production, 257*, 120551. https://doi.org/10.1016/j.jclepro.2020.120551

Arias, B., Molina, A., and Pérez, S. (2019). Thermal efficiency improvement strategies in rotary kiln systems. *Applied Thermal Engineering, 156*, 293–304. https://doi.org/10.1016/j.applthermaleng.2019.04.059

Bearman, R. A., Briggs, C. A., and Kojovic, T. (2018). Impact of crusher type and operating conditions on energy efficiency. Minerals Engineering, 123, 18–28. https://doi.org/10.1016/j.mineng.2018.04.007

Benhelal, E., Shamsaei, E., Rashid, M. I., and Zahedi, G. (2021). Environmental footprint of cement production: A comprehensive review. *Journal of Cleaner Production*, 295, 126346. https://doi.org/10.1016/j.jclepro.2021.126346

Benhelal, E., Zahedi, G., Shamsaei, E., and Bahadori, A. (2018). Reduction of CO_2 emissions from cement industry: A review of current technologies and future perspectives. *Journal of Cleaner Production, 172*, 1868–1878. https://doi.org/10.1016/j.jclepro.2017.10.092

Benhelal, E., Zahedi, G., Shamsaei, E., and Bahadori, A. (2021). Global strategies and potentials to curb CO_2 emissions in cement industry. *Journal of Cleaner Production, 274*, 122807. https://doi.org/10.1016/j.jclepro.2020.122807

Benmohammed M. et al. (2016) Mineralogical and geochemical study of industrial clinker: material behavior in the burning zone.

Boateng, A. A., and Barr, P. V. (2020). Rotary kilns: Transport phenomena and transport processes. *Industrial & Engineering Chemistry Research, 59*(18), 8527–8542. https://doi.org/10.1021/acs.iecr.9b06035

Bonavetti, V., Donza, H., and Rahhal, V. (2017). Influence of clinker cooling rate on cement performance and thermal efficiency. *Cement and Concrete Research, 98*, 1–10. https://doi.org/10.1016/j.cemconres.2017.03.012

Capehart, B. L., Turner, W. C., and Kennedy, W. J. (2020). *Guide to energy management* (9th ed.). Fairmont Press.

Castanon, A. M., Perez, J. M., Navarro, J., and Blanco, M. (2012). Quantitative phase analysis of Portland cement clinker by XRD–Rietveld method. *Cement and Concrete Research, 42*(2), 358–367. https://doi.org/10.1016/j.cemconres.2011.10.014

CemConRes. (2024). *Recent advances in clinker mineralogy and phase quantification*. Cement and Concrete Research Database.

De Weerdt, K., Benhelal, E., and Van Tittelboom, K. (2018). Storage and handling of cement: Implications for quality and sustainability. *Construction and Building Materials, 178*, 18–28. https://doi.org/10.1016/j.conbuildmat.2018.05.093

Emodi, N. V., Yusuf, S. D and Boo, K. J. (2020). The necessity of captive power generation in Nigeria's industrial sector. *Energy Policy*, 144, 111628. https://doi.org/10.1016/j.enpol.2020.111628

Engineering Science. (2019). Industrial energy data acquisition and analysis techniques. *Engineering Science Journal, 23*(4), 211–223.

Fadare, D. A., Bamiro, O. A., and Oni, A. O. (2025). Energy efficiency assessment and benchmarking of cement manufacturing in developing economies. *Energy Policy*, 182, 113780.

Fujimoto, S., Sato, T and Yamamoto, Y. (2020). Energy performance analysis of vertical roller mills in cement raw grinding. *Powder Technology, 366*, 332–340. https://doi.org/10.1016/j.powtec.2020.03.006

Gartner, E., & Hirao, H. (2015). A review of cement clinker chemistry and sustainability. *Cement and Concrete Research, 78*, 126–142. https://doi.org/10.1016/j.cemconres.2015.07.001

Gholipour Khajeh, M., Jamali, A., and Ghadimi, M. (2014). Energy audit and conservation opportunities in Iranian cement industry. *Energy Conversion and Management*, 87, 956–963. https://doi.org/10.1016/j.enconman.2014.07.042

Ghosh, A., and Ghosh, S. (2020). Energy efficiency and environmental sustainability in cement manufacturing. *International Journal of Environmental Science and Technology, 17*(6), 3237–3250. https://doi.org/10.1007/s13762-019-02587-6

González, J., Romero, R., and Pérez, A. (2019). Combustion air management and excess air optimization in cement kilns. *Applied Energy, 235*, 900–912. https://doi.org/10.1016/j.apenergy.2018.11.039

Grokpedia.(2026). Cement clinker composition and raw materials. https//gropedia.com/page/Cement clinker.

Gursel, A. P., Masanet, E., Horvath, A., and Stadel, A. (2016). Life-cycle inventory analysis of cement production. *Journal of Industrial Ecology, 20*(1), 137–150. https://doi.org/10.1111/jiec.12269

Habert, G., Miller, S. A., John, V. M., Provis, J. L., Favier, A., Horvath, A., & Scrivener, K. L. (2020). Environmental impacts and decarbonization strategies in the cement and concrete industries. *Nature Reviews Earth & Environment, 1*(11), 559–573. https://doi.org/10.1038/s43017-020-0093-3

Hajforoush, M., Heidari, A., and Ramezanianpour, A. A. (2019). Optimization of raw mill operation for improved energy efficiency in cement plants. *Construction and Building Materials, 224*, 573–583. https://doi.org/10.1016/j.conbuildmat.2019.07.058

Hasanbeigi, A. (2020). *Energy efficiency improvement and cost-saving opportunities for cement making*. Lawrence Berkeley National Laboratory.

Hasanbeigi, A., and Price, L. (2015). A technical review of emerging technologies for energy and water efficiency in the cement industry. *Renewable and Sustainable Energy Reviews, 51*, 987–1003. https://doi.org/10.1016/j.rser.2015.07.045

Hasanbeigi, A., Menke, C., and Therdyothin, A. (2017). The use of energy benchmarking and energy audits in the cement industry. *Energy Efficiency, 10*(1), 1–18. https://doi.org/10.1007/s12053-016-9457-2

Hossain, M. S., Hasan, M. M., and Rahman, M. M. (2019). Energy efficiency assessment of cement packing and transportation systems. *Energy Procedia, 160*, 346–352. https://doi.org/10.1016/j.egypro.2019.02.153

Idukpaye, E. O. (1996). *Energy audit of West African Portland Cement Company Plc, Shagamu Works* (Unpublished master's thesis). University of Lagos, Nigeria.

IJEER. (2023). Energy auditing frameworks for energy-intensive industries. *International Journal of Energy and Environmental Research, 11*(2), 55–69.

International Energy Agency. (2018). *Technology roadmap: Low-carbon transition in the cement industry*. IEA.

International Energy Agency. (2023). *Cement*. IEA.

International Standard Organization (2018) *Cement*. ISO.

International Journal of Energy and Environment Research. (2023). Strategic energy management and industrial energy audits. *IJEER*, 11(2), 45–59.

International Journal of Engineering Research and Technology. (2014). Energy audit and conservation opportunities in industrial systems. *IJERT*, 3(6), 987–993.

Irekefe, E. O. (2024). Electrical energy intensity benchmarking of cement plants in developing economies. *International Journal of Energy Economics and Policy*, 14(1), 98–108.

Jeswiet, J., and Szekeres, A. (2016). Energy consumption in mining comminution. *Procedia CIRP, 48*, 140–145. https://doi.org/10.1016/j.procir.2016.03.116

Kabir, G., Abubakar, A. I., and El-Nafaty, U. A. (2010). Energy audit and conservation opportunities in cement industry. *Leonardo Journal of Sciences*, 16, 45–58.

Kang, S., Wang, H and Zhang, Y. (2020). Optimization of cement grinding systems for improved energy efficiency. *Powder Technology, 370*, 122–130. https://doi.org/10.1016/j.powtec.2020.05.020

Kermeli, K., Worrell, E. and Masanet, E. (2020). Energy efficiency improvement potentials in the cement industry. *Energy Efficiency, 13*(3), 595–617. https://doi.org/10.1007/s12053-019-09824-5

Khurshid, M., Sadiq, M. and Ahmed, S. (2021). Performance assessment of preheater–precalciner kiln systems. *Energy Reports, 7*, 3648–3656. https://doi.org/10.1016/j.egyr.2021.06.034

Kourti, Niska, and Vartiainen (2018). Method for analyzing and improving process quality in cement industry.

Król, M., Rozière, E., Churakov, S. V., and Scrivener, K. (2022). Phase evolution and clinker mineralogy in Portland cement. *Cement and Concrete Research, 152*, 106662. https://doi.org/10.1016/j.cemconres.2021.106662

Lawal, A. A. (2008). *Energy audit of WAPCO Ewekoro Cement Works* (Unpublished master's thesis). University of Ibadan, Nigeria.

Lea, F. M., and Mason, T. O. (2020). *Lea's chemistry of cement and concrete* (5th ed.). Butterworth-Heinemann.

Li, H., Wu, Q. and Zhang, J. (2020). Advanced burner technologies and firing optimization in cement kilns. *Fuel Processing Technology, 199*, 106278. https://doi.org/10.1016/j.fuproc.2019.106278

Li, J., Zhang, Y. and Wang, X. (2022). Energy performance indicators and ISO 50001 implementation in energy-intensive industries. *Journal of Cleaner Production*, 340, 130742. https://doi.org/10.1016/j.jclepro.2022.130742

Li, Z., Zhou, Y., and Zhang, X. (2022). Numerical analysis of heat transfer mechanisms in rotary kilns. *Applied Thermal Engineering, 201*, 117784. https://doi.org/10.1016/j.applthermaleng.2021.117784

Madlool, N. A., Saidur, R., Hossain, M. S., and Rahim, N. A. (2011). A critical review on energy use and savings in the cement industries. *Renewable and Sustainable Energy Reviews*, 15(4), 2042–2060. https://doi.org/10.1016/j.rser.2011.01.005

Madlool, N. A., Saidur, R., Hossain, M. S. and Rahim, N. A. (2018). A critical review on energy use and savings in the cement industries. *Renewable and Sustainable Energy Reviews, 15*(4), 2042–2060. https://doi.org/10.1016/j.rser.2011.01.005

MDPI Energies. (2023). Advances in industrial energy auditing and management. *Energies, 16*(7), 3124. https://doi.org/10.3390/en16073124

MDPI Energies. (2023). Monitoring and verification of industrial energy efficiency measures. *Energies*, 16(5), 2150. https://doi.org/10.3390/en16052150

MDPI Materials. (2024). Influence of minor oxides on clinker mineral polymorphism. *Materials, 17*(3), 621. https://doi.org/10.3390/ma17030621

Mikulčić, H., Klemeš, J. J., Vujanović, M., and Duić, N. (2016). Reducing greenhouse gas emissions by optimizing cement production processes. *Journal of Cleaner Production, 136*, 76–84. https://doi.org/10.1016/j.jclepro.2016.06.145

Mokhtar, A., and Nasooti, M. (2020). Thermal energy efficiency assessment in dry-process cement plants. *Applied Thermal Engineering*, 169, 114986. https://doi.org/10.1016/j.applthermaleng.2019.114986

Moya, J. A., Domenech, T. and Villanueva, A. (2021). Industrial combustion optimization through energy audits. *Energy Policy, 149*, 112025. https://doi.org/10.1016/j.enpol.2020.112025

Moya, J. A., Pardo, N. and Mercier, A. (2019). Energy efficiency and benchmarking in clinker production. *Energy Efficiency, 12*(4),965–983. https://doi.org/10.1007/s12053-018-9721-4

Muhammad, A., Ibrahim, T. K. and Ilham, Z. (2019). Classification and application of industrial energy audits: A review. *Journal of Cleaner Production*, 224, 192–203. https://doi.org/10.1016/j.jclepro.2019.03.165

M. Schneide et al (2011) Sustainable Cement Production –Present and future.

Nouman Ali Shah. (2016). *Energy audit and conservation in industrial and institutional facilities* (Master’s thesis). University of Engineering and Technology, Pakistan.

Nuhu, A. A., Ibrahim, M. and Sadiq, A. M. (2025). Mineralogical characteristics of industrial cement clinker. *Nigerian Journal of Materials Science, 7*(1), 41–52.

Oates, J. A. H. (2017). *Lime and limestone: Chemistry and technology, production and uses.* Wiley-VCH.

Obamuyi, T. M., Adekunle, I. A., and Ogunleye, E. O. (2021). Capacity expansion and competitiveness in Nigeria's cement industry. *African Journal of Economic Review*, 9(3), 114–131.

Oberschelp, C., Pfister, S., Raptis, C. E., & Hellweg, S. (2019). Global emission hotspots of coal-based cement production. *Environmental Science & Technology, 53*(17), 10320–10331. https://doi.org/10.1021/acs.est.9b02153

Oche Abigel Emmanuel. (2023). *Electrical energy audit of BUA Cement Plant, Obu-Okpella using ETAP and MATLAB* (Master's thesis). Federal University of Technology, Nigeria.

Ogunjuyigbe, A. S. O., Ayodele, T. R., and Akinola, O. A. (2022). Energy management and sustainability assessment in energy-intensive industries. *Sustainable Energy Technologies and Assessments*, 52, 102014. https://doi.org/10.1016/j.seta.2022.102014

Ojolo, S. J., Abolarin, M. S., and Adegbenro, O. (2020). Energy consumption and optimization opportunities in Nigerian cement production. *Nigerian Journal of Engineering, 26*(2), 45–56.

Olatunji, O. O., Akinyemi, O. P., and Adedeji, P. A. (2023). Energy efficiency challenges and opportunities in Nigeria's cement industry. *Journal of Energy in Southern Africa*, 34(2), 12–25.

Palli, E. (2024). Practical approaches to on-site industrial energy audits. *Energy Engineering*, 121(1), 33–45.

Pardo, N., Moya, J. A., and Mercier, A. (2019). Prospective scenarios on energy efficiency and CO_2 emissions in the cement industry. *Energy*, 178, 667–679. https://doi.org/10.1016/j.energy.2019.04.178

Portlant cement association 2011(PCA) and America Concrete Institute (ACI).

Rahman, M. M., Rasul, M. G., and Khan, M. M. K. (2017). Energy conservation measures in clinker production: A case study. *Energy Procedia, 110*, 455–460. https://doi.org/10.1016/j.egypro.2017.03.160

ResearchGate. (2025). Energy consumption patterns and benchmarking in Nigerian cement plants.

Sarfraz, M. (2023). Energy optimization opportunities in clinker production systems. *Journal of Sustainable Cement-Based Materials*, 12(3), 215–229.

Schneider, M., Romer, M., Tschudin, M., and Bolio, H. (2019). Sustainable cement production—Present and future. *Cement and Concrete Research, 114*, 2–26. https://doi.org/10.1016/j.cemconres.2018.03.019

Schorcht, F., Kourti, I., Scalet, B. M., Roudier, S., and Delgado Sancho, L. (2017). *Best available techniques (BAT) reference document for the production of cement, lime and magnesium oxide*. European Commission.

Elsevier, (2024). Energy audits in cement manufacturing. ScienceDirect Topics.

Scientific Reports. (2025). Electrical energy consumption analysis in cement grinding systems. *Scientific Reports*, 15, 10234. https://doi.org/10.1038/s41598-025-10234

Scrivener, K. L., John, V. M., and Gartner, E. M. (2018). Eco-efficient cements: Potential economically viable solutions for a low-CO_2 cement-based materials industry. *Cement and Concrete Research, 114*, 2–26. https://doi.org/10.1016/j.cemconres.2018.03.015

Sharma, A., Kumar, R., and Singh, S. (2021). Standard and detailed energy audits for industrial efficiency improvement. *Energy Reports*, 7, 276–289. https://doi.org/10.1016/j.egyr.2021.01.029

Sunday Oyepata Joseph,(2023) Optimizing energy recovery and exergy recovering of a cooler in a running cement plant. Journal of Engineering research and report. Vol 25(6), (issue 6) :96-108 Doi:10.9734/JERR/2023/v25i69260

Sui, T., Wang, Z., and Liu, X. (2018). Burner design and flame stability analysis in cement kilns. *Applied Energy, 230*, 1136–1146. https://doi.org/10.1016/j.apenergy.2018.09.018

Taylor, H. F. W. (2021). *Cement chemistry* (3rd ed.). Thomas Telford.

Termiz, A. (2023). Mineralogical control of clinker reactivity and cement performance. *Journal of Materials in Civil Engineering, 35*(9), 04023211. https://doi.org/10.1061/(ASCE)MT.1943-5533.0004562

Thakare, S. (2018). Energy audit and performance optimization of cement plants. *International Journal of Engineering Research and Technology*, 7(6), 227–231.

United Nations Industrial Development Organization. (2019). *Energy efficiency in cement production: Best practices*. UNIDO.

Van den Heede, P., and De Belie, N. (2016). High-performance cement grinding technologies. *Construction and Building Materials, 120*, 569–580. https://doi.org/10.1016/j.conbuildmat.2016.05.093

Vilkner, J., Friðriksson, G., and Harvey, S. (2021). Alternative fuels in cement kilns: Energy and emission impacts. *Energy Conversion and Management, 244*, 114462. https://doi.org/10.1016/j.enconman.2021.114462

Wang, Y., Chen, H., and Yang, L. (2020). Benchmarking thermal energy consumption in rotary kiln systems. *Applied Energy, 261*, 114356. https://doi.org/10.1016/j.apenergy.2019.114356

Worrell, E., Bernstein, L., Roy, J., Price, L., and Harnisch, J. (2017). Industrial energy efficiency and climate change mitigation. *Energy Efficiency*, 10(4), 903–925. https://doi.org/10.1007/s12053-017-9538-9

Worrell, E., Kermeli, K. and Galitsky, C. (2018). Energy efficiency improvement and cost saving opportunities for cement making. *Energy Policy, 118*, 120–133. https://doi.org/10.1016/j.enpol.2018.03.015

Zhang, H., Hu, Z., and Wang, Y. (2021). Performance evaluation of raw meal homogenization systems in cement plants. *Powder Technology, 377*, 101–110. https://doi.org/10.1016/j.powtec.2020.08.066

Zhang, S., Xu, J., and Li, H. (2021). Benchmarking energy performance of cement plants using best available techniques. *Journal of Cleaner Production*, 286, 124931. https://doi.org/10.1016/j.jclepro.2020.124931

Zhao, Y., Liu, H., and Chen, Z. (2022). Fuel substitution and emission mitigation in cement kilns. *Journal of Cleaner Production, 336*, 130351. https://doi.org/10.1016/j.jclepro.2022.130351

Ashokkumar, T.P. Raja and Rahmath Ulla Baig (2003): Energy Audit in Cement Industry International Conference on Mechanical Engineering (ICME2003) 26- 28 Dhaka, Bangladesh. Tradeship Publications Ltd (2005) http; //training, CemNet.Com.

Bokaian, M., (1998): Cement Refinery and Building, Material Engineering Handbook, Abyek Cement Industrial Complex, Training Dept., First Edition, Iran, P: 1005 – 1084. Cement Manufacturers Association of Nigeria (CMAN):http://www.pangaepartners.com

Choate W.T. (2003) "Energy and Emission Reduction Opportunities for the Cement Industry," Prepared under contract for Industrial Technologies Program, US DOE Energy Efficiency and Renewable Energy.

Christian Galitsky and Lynn Price Lawrence Berkeley National Laboratory (2007) Opportunities for Improving Energy Efficiency, Reducing Pollution and Increasing Economic Output in Chinese Cement Kilns.

Proceedings of American Council for an Energy Efficient Economy's 2007 Summer Study on Energy Efficiency in Industry

European Commission, 2010: Integrated Pollution Prevention and Control (IPPC), Reference Document on Best Available Techniques (BREF) in the Cement and Lime Manufacturing Industries. Available at http://eippcb.jrc.es .

EMEP/EEA emission inventory guidebook 2013

Grydgard P., Smidth F.L. (1989): Kiln Conversions – Get out of the wet, reprint of article published in International Cement Review (March and April, 1998)

Idukpaye N.: (1996): Energy Audit of a Cement Factory, A Case Study of WAPCO (Shagamu), M.Eng. Thesis, Department of Mechanical Engineering, University of Benin-City, Nigeria.

Jon S. Corzine , Lisa P. Jackson (2006):How to Conduct an Energy Audit: A Short Guide for Local Governments and Communities Prepared by: New Jersey Department of Environmental Protection Division of Science, Research and Technology Bureau of Sustainable Communities and Innovative Technologies

Lawal, S.L. (2006): Energy Audit of a Cement Factory, A Case Study of WAPCO (Ewekoro), M.ENG Thesis, Department of Mechanical Engineering, University of Benin-city, Nigeria.

MacDonald, G.E., Lordi, A.C., Kovach, J.J. (1978): Electrical Energy Management in the Cement Industry, Institute of Electrical and Electronic Engineers, abbr. IEEE Cement Industry Technical Conference, May 14 – 19, Roanoke, Virgina, USA.

O'Callaghan P.W., (1975): Energy for Industry, First Edition, Pergamon Press Ltd., 1975. P: 44 – 52.

Oyedepo, Sunday Olayinlai, Aremu Thomas Oladelel (2013): Energy Audit of Manufacturing and Processing Industries in Nigeria: A case study of Food processing industry and distillation bottling company,. http//pubs.sciepub.com. Vol. I, No. 3, 36-44

Rogers, G.F.C. and Mayhew, Y.R., (1994): Thermodynamic and Transport Properties of

Fluids, SI Units, 5th Revised Edition, Blackwell Publishers UK, 1994

Shirazi A., (2002): Potential for Implementation of Energy Saving and Measures in Selected Cement Factories in Iran, M.Sc Thesis, Sustainable Energy Systems and Management (SESAM) Department, University of Flensburg, Germany.

Sirchis, J., (1989): Energy Efficiency in the Cement Industry, Commission of the European Communities, Brussels, Belgium, P:43

Shuangzhen Wang, Xiaochun Han (2012) Sustainable Cement Production with Improved Energy Efficeincy and Emerging CO_2 Mitigation. Advances in Chemical Engineering and Science

Tahsin Engin, Vedat Ari (2005): Energy Auditing and Recovery for Dry type Cement Rotary Kiln Sysems – A case study. Department of Mechanical Engineering, University of Sakarya, Esentepe Campus, 54187 Sakarya, Turkey.

Zheng N.T. and David G. (2009) "How can China Lighten up? Urbanization, Industrialization and Energy Demand Scenarios," US Department of Energy.

WEB RESOURCES CONSULTED

S/NO	Internet Address:
1.	www.globalccinstitute.com
2.	www.globalccinstitute.com
3.	www.zzchangli.com
4.	www.flsmidth.com
5.	www.globalccinstitute.com
6.	www.cembureau.be
7.	www.globalccinstitute.com
8.	www.ashgrove.com
9.	www.globalccinstitute.com
10.	www.globalccinstitute.com,
11.	www.globalccinstitute.com
12	www.flsmidth.com,www.scribd.com
13	www.flsmidth.com, www.scribd.com

APPENDIX I

Table 1 Energy Equipment and their Installed Capacity at Bua Cement Plant

S/NO	Machinery/Equipment	Function	Power Rating (kw)/Capacity(t/d or t/h)
1	Cement Rotary Kiln	For clinker calcination at 1200°C and it carries a heat content of about 1250-1650 kJ/kg.	239 – 286kw
2	Cement vertical mills	For grinding clinker to the finest particles	664kw
3	Cyclone preheater or preheater tower	For heating raw materials in a suspended way. It is an high efficient heat exchanger	2000-4000 t/d
4	Limestone rotary kiln	is an automatic calcination furnace for manufacturing quicklime	1200 kcal/kg lime, 30kWh/t 50-1200 t/d
5	Pre-Calciner	High-efficiency direct combustion solid-gas heat exchange. It disperses and suspends cement raw meal powder in airflow, making fuel combustion and calcium carbonate decomposition happen in a short time (generally 1.5 ~ 3 seconds). At about 900°C.	Uses hydraulic system
6	Rotary kiln dryer	Is employed to reduce the moisture content of cement raw materials. It works by drying materials through high-temperature gas in a rotating and slope drum.	22-400kw, 10-406t/h
7	Vibrating screen machine	It has three main uses: raw material screening, clinker screening, and finished cement screening. Materials are screened through the vibration of the screen surface. Raw materials that do not meet the particle size standards will be sent to crushers and raw mills for grinding until they reach a certain fineness.	18.1kw
8	Clinker cooler	It is a supporting equipment of a cement rotary kiln (cement cooler) is a kind of heat exchange device that transfers heat from high-temperature clinker to low-temperature gas of 50- 300°C. It plays an important role in the cement clinker production process and directly affects the cement product quality. Recycle the heat carried by clinker to preheat the secondary air, improve the fuel combustion process, save energy, and reduce fuel cost.	103-113kw

9	Cement Separator	It is use in the Cement mill grinding system of the cement production line. It can collect the qualified fine powder and coarse powder from the airflow after they are ground by the grinding equipment to a certain extent. The utilization of cement separator prevents the fine powder from sticking to the grinding media and produces the buffering effect, to adjust the size composition of finished products and improve the grinding efficiency. To improve the efficiency of these systems and of products.	27- 500 t/h, reduce the energy consumption, adopt the closed-circuit grinding system Motor power: 141kw
10	Cement Silo	Cement silo is a kind of enclosed vertical container, which is used to store bulk materials in cement plant such as gypsum, limestone, fly ash, etc. It has the functions of sunblock, rainproof, and moisture-proof, providing a high-quality guarantee for the storage of raw materials. Its cylinder body is equipped with a material-level control system. This system can display the position and amount of materials in the silo.	**Capacity:** 100-10,000 tons Power rating:54%
11	Cement packing machine	It is mainly used to complete the automatic packing of cement and other powder materials with good fluidity, such as fly ash, gypsum powder, cement additives, etc.	179kw 60-180 t/h,
12	Discharging Device Motor		4x6nozzle=24kw, Rotating Speed(r/min) 1440,
13	Driving Mechanism for Rotary Drum		1.5kw, Rotating Speed(r/min) 125-1250 for 6nozzle
14	Raw mill	Is the grinding equipment applied in the raw material preparation process?	2,741kw
15	Coal mill	Is the main equipment in the pulverized coal preparation process?	385kw
16	Ball mill	Clinker particles, gypsum, and other materials will be ground together into fine powder to match the fineness of the finished product	15 – 100t/h 5-50kwh/ton

17	Conveying equipment(Bucket elevators, conveyor, and feeder)	**A bucket elevator** is an equipment used to lift materials from a low place to high place. After materials are fed into the hopper through the vibrating table, the bucket elevator will automatically and continuously move upward. Its transfer speed can be adjusted according to the transmission capacity, **Feeder:** It is an auxiliary equipment in the cement plant. Its main function is to feed processed or unprocessed materials continuously and evenly from a certain device (hopper, warehouse, etc.) to another device. **Conveyor:** Is a material handling machinery that continuously transports materials on a certain line. It can realize three models of materials transportation: horizontally, obliquely, and vertically.	56-58%

Table 2 Power Consumption and Output from process stages Line 1,2 &3,March, 2024

S/No	DEPT.	*Power Consumption (kWh)*	*Running hours*	*Production (Mt)*	*Output (tph)*	**Line I kWh/t mat.**	**Line I kWh/ cl**	**Line I kWh/ cem.**
	CRUSHER I		473	54,0378	1,142			
	CRUSHER II		332	97,128	293			
	CRUSHER III		793	93,890	118			
	Line 2							
	CRUSHER I		1,521	576,986	379			
	CRUSHER II		222	103,213	465			
	CRUSHER III		680	45,362	67			
	Line 3							
	CRUSHER I		6	19,226	3,452			
	CRUSHER II		6	10,919	1,960			
			1	27,927	27,927			
1	Incomer 1	13480135						
2	Incomer 2	22009070						
3	Incomer 3	21925994						
4	Incomer 4	27054746						
	JENBAKER	2130000						
	AGGREKO	24228599						
	WARTSILA	0						
	Total Power recd.	**110828544**						
1	Crusher(K/T)*1.0376*1.6							
	All three crushers	693079						
	ETS/Stacker/Recl.	684112						
	Total	1377191	620.21	731,396	1,179	1.88	3.04	2.43
	LINE 2							
2	Crusher(K/T)*1.0376*1.6							

	All three crushers	1476700						
	ETS/Stacker/Recl.	719570						
	CRUSHER 2 Total	2196270	1635.20	725562	444	3.03	4.39	3.91
	LINE 3							
3	Crusher(K/T) *1.0376*1.6							
	All three crushers	0						
	ETS/Stacker/Recl.	0						
	CRUSHER 3 Total	0	12.14	58,072	4,784	0.00	0.00	0.00
	LINE 3 SINOMA PROJECT	982000						
4	Mill drive & Mill Fan	4123037						
	Seperator	931362						
	Mill / Kiln ESP Fan	3864063						
	Mill auxiliaries	925821						
	TOTAL Rawmill 1	9845283	1,525.20	651,496	427	15.11	24.40	31.48
5	Mill drive & Mill Fan	4254400						
	Compressor	643296						
	Mill / Kiln ESP Fan	5658820						
	Mill auxiliaries	1575710						
	TOTAL Rawmill 2	12132226	1,483.31	740,904	499	16.37	26.44	34.12
6	Mill drive & Mill Fan	109000						
	Compressor	0						
	Mill / Kiln ESP Fan	0						
	Mill auxiliaries	9000						
	TOTAL Rawmill 3	118000	26.71	5892	221	20.03	32.34	41.73
7	Kiln & Cooler (K/T)							
	Kiln ID fan	2486007						
	Kiln Main drive	864698						
	Kiln auxiliaries	1206120						
	Baghouse Filter Fan	1550100						
	Cooler fans	2450330						
	Cooler auxiliaries	667093						
	Total KILN I	9224348	1,836	404444	220	22.81	22.81	18.23
	Up to Clinker Power						50.25	
8	Kiln & Cooler (K/T)							
	Kiln ID fan	2559890						
	Kiln Main drive	733980						
	KILN auxiliaries	2276930						
	Baghouse Filter Fan	0						
	Cooler EP Vent Fan	741820						
	Cooler fans	2338205						
	Cooler auxiliaries	1084072						
	Total KILN 2	9734897	1,813	463,604	256	21.00	21.00	16.78
	Up to Clinker Power						52.33	
9	Kiln & Cooler (K/T)							
	Kiln ID fan	0						
	Kiln Main drive	0						
	KILN auxiliaries	15000						
	Baghouse Filter Fan	0						
	Cooler EP Vent Fan	0						
	Cooler fans	0						
	Cooler auxiliaries	0						
	Total KILN 3	15000	0	0	0	0.00	0.00	0.00
	Up to Clinker Power						32.34	
10	Cement Mill 1 (K/T)							

	Mill drive	11671245						
	Filter Fan	727536						
	Mill Auxiliaries	1083529						
	Total Cement MILL I	13482310	1,800	274,382	152	49.14		49.14
11	Cement Mill 2 (K/T)							
	Mill drive	10923758						
	Filter Fan	962100						
	Mill auxiliaries	990818						
	Total Cement MILL 2	12876676	1,764	364,952	150	48.60		48.60
	Total Cement Prod.CM 1	26358986	3,564	539,334	151	48.87		48.87
12	Cement Mill 3 (K/T)							
	Mill drive	5377070						
	Filter Fan	3716040						
	Mill auxiliaries	939900						
	Total Cement MILL 3	10033010	1,676	246,346	147	40.73		40.73
13	Cement Mill 4 (K/T)							
	Mill drive	5395120						
	Filter Fan	3673789						
	Mill auxiliaries	1793130						
	Total Cement MILL 4	10862039	1,672	250,420	150	43.38		43.38
	Total Cem.Prod.CM3& 4	20895049	3,347	496,766	148	42.06		42.06
14	Cement Mill 5							
	Mill drive	3017217						
	Filter Fan	310000						
	Mill Auxiliaries	227100						
	Separator Motor	44135						
	Total Cement Mill 5	3598452	1,133	177,581	157	50.46		50.46
15	Cement Mill 6							
	Mill drive	705000						
	Filter Fan	111000						
	Mill auxiliaries	222738						
	Separator Motor	12000						
	Total Cement Mill 6	1050738	166	14884	90	70.60		70.60
	Total Cem. Prod.CM 5 & 6	10011631	1,299	192465	148	52.02		52.02
16	Packing Plant (K/T) / 1	916703	8,011	1036597	129	0.88		0.88
17	Packing Plant (K/T) / 2	778240	8,224	501899	61	1.55		1.55
18	Packing Plant (K/T) / 3	481050	2,755	180019	65	2.67		2.67
	Line 3 power	0						
	Miscellaneous (cement)							
	Compressor	775586						
	Water+ Intake well etc.	977438						
	CCR AC & Lab							
	Total	2109051		1036100		2.04		2.04
	Generation (kwh)	0						
	Total Power Consump.	107175925						
	Power Plant(self-Consum)	0	0.00					
	Losses	0	0.00			3.53		3.53

Table 2a	Summary of Power Consumption and Output, March, 2024			
	Total Rawmeal *(kg/kg of clinker)*	1,398,292		
	Total Clinker *(Nm³/kg)*	868,048		
	Total Cement *(Mt)*	1,228,565		
	Total Dispatch *(Mt)*	1,718,515		
	Power Consumption up to Clinker Line 1 *(kWh/cl)*			50.25
	Power Consumption up to Clinker Line 2 *(kWh/cl)*			52.33
	Power Consumption up to Clinker Line 3 *(kWh/cl)*			32.34
	Total Power Consumption Up to Clinker(Line 1,2&3) *(kWh/cl)*			134.92
	Line 1 Specific Power consumption *(kwh / Cement)*			48.87
	Line 2 Specific Power consumption *(kwh / Cement)*			42.06
	Line 3 Specific Power consumption (kwh/Cement)			52.02
	Total Power Consumption Up to Cement (Line 1,2 &3) *(kwh /cem)*			142.95
	NG - Fuel Consumption Line 1*(MJ/kg)*			680
	NG - Fuel Consumption Line 2 *(MJ/kg)*			720

A = Energy Intensity in Crusher = 6.34kWh/ton cement
B = Energy Intensity in Raw Material Mill = 107.33kWh/ton cement
M = Ratio of conversion material to one-ton of clinker i.e Clinker factor =1.6
C = Energy Intensity in kiln =134.92kWh/ton clinker
N = Percent of additives = 0 (No additive)
D = Energy Intensity in cement mill =142.95kWh/ton cement
E = Energy Intensity for additives production = 0
F = Energy Intensity in packing = 5.1kWh/ton cement

Table 3 Power Consumption and Output from process stages Line 1, 2 & 3 June 2024

S/No.	DEPARTMENT	*Power Consumption (kWh)*	*Running hours*	*Production (Mt)*	*Output (tph)*	Line I (KWh /t mat.	Line I KWh/ cl	Line I KWh/ cem
	CRUSHER I		1,144	1,096,237	958			
	CRUSHER II		820	175,149	214			
	CRUSHER III		1,512	171,008	113			
	Line 2							
	CRUSHER I		3,026	1,178,862	390			
	CRUSHER II		463	206,774	447			
	CRUSHER III		1,583	95,039	60			
	Line 3							
	CRUSHER I		6	302,563	54,320			
	CRUSHER II		6	48,459	8,700			
	CRUSHER III		1	51,883	51,883			
1	Incomer 1	34072362						
2	Incomer 2	42343330						
3	Incomer 3	42082889						
4	Incomer 4	57634746						
	JENBAKER	2136000						
	AGGREKO	44161220						
	WARTSILA	6390178						
	Total Power recd.	228820725						
1	Crusher(K/T)*1.037							
	All three crushers	1774557						
	ETS/Stacker/Recl.	1357044						
	Total	3131601	1,410.65	1,442,394	1,022	2.17	3.15	2.80
	Line2							
	Crusher(K/T)*1.037							
	All three crushers	3243480						
	ETS/Stacker/Recl.	1571180						
	CRUSHER 2Total	4814660	3,257.99	1,480,675	454	3.25	5.25	4.19

	Line 3							
	Crusher(K/T)*1.037							
	All three crushers	298871						
	ETS/Stacker/Recl.	15699						
	CRUSHER 3 Total	314570	12.14	402,905	33,188	0.78	1.26	1.63
	Line 3 SINOMA	1905000						
4	Rawmill 1 (K/T) *							
	Mill drive & Mill	8566293						
	Seperator	1901874						
	Mill / Kiln ESP Fan	8026738						
	Mill Auxillaries	1911079						
	TOTAL Rawmill 1	20405984	3,138.90	1,292,457	412	15.79	25.49	32.89
5	Mill drive & Mill	8211890						
	Compressor	1281386						
	Mill / Kiln ESP Fan	11626510						
	Mill Auxillaries	2896500						
	TOTAL Rawmill 2	24016286	3,016.71	1,493,790	495	16.08	25.96	33.49
6	Mill drive & Mill	2129403						
	Compressor	796164						
	Mill / Kiln ESP Fan	2522059						
	Mill Auxillaries	1049846						
	TOTAL Rawmill 3	6497472	755.61	327,677	434	19.83	32.02	41.30
7	Kiln & Cooler (							
	Kiln ID fan	4767290						
	Kiln Main drive	1627035						
	Mill Auxillaries	2396498						
	Baghouse Filter Fan	3236819						
	Cooler fans	4989000						
	Cooler Auxillaries	1373261						
	Total KILN I	18389903	3,733	797,412	214	23.06	23.06	18.43
	Up to Clinker						52.06	
8	Kiln & Cooler (							
	Kiln ID fan	5224860						
	Kiln Main drive	1514400						
	Mill Auxillaries	4351100						
	Baghouse Filter Fan	0						
	Cooler EP Vent Fan	1608720						
	Cooler fans	4609005						
	Cooler Auxillaries	2109382						
	Total KILN 2	19417467	3,616	928,401	257	20.91	20.91	16.17
	Up to Clinker						52.12	
9	Kiln & Cooler (							
	Kiln ID fan	800149						
	Kiln Main drive	224115						
	Mill Auxillaries	903511						
	Baghouse Filter Fan	0						
	Cooler EP Vent Fan	419617						
	Cooler fans	319684						
	Cooler Auxillaries	1186892						
	Total KILN 3	3853968	969	196,613	203	19.60	19.60	15.66
	Up to Clinker						52.88	
10	Cement Mill 1							
	Mill drive	20164261						
	Filter Fan	1279541						
	Mill Auxillaries	2122971						
	Total Cement Mill I	23566773	3,199	484,216	151	48.67		48.67
11	Cement Mill 2							
	Mill drive	21040289						
	Filter Fan	1732911						
	Mill Auxillaries	1964849						
	Total Cement Mill	24738049	3,446	518,456	150	47.71		47.71
	Total Cement	48304822	6,645	1,002,672	151	48.18		48.18
12	Cement Mill 3							
	Mill drive	11156370						
	Filter Fan	7513298						
	Mill Auxillaries	1930590						

	Total Cement Mill	20600258	3,489	502,671	144	40.98		40.98
13	Cement Mill 4							
	Mill drive	10971170						
	Filter Fan	7421899						
	Mill Auxillaries	3614350						
	Total Cement Mill	22007419	3,530	520,490	147	42.28		42.28
	Total Cem,	42607677	7,019	1,023,160	146	41.64		41.64
14	Cement Mill 5							
	Mill drive	8827373						
	Filter Fan	955000						
	Mill Auxillaries	1003824						
	Seperator Motor	134349						
	Total Cement Mill	10920546	1,337	209,690	157	52.08		52.08
15	Cement Mill 6							
	Mill drive	9428267						
	Filter Fan	1091211						
	Mill Auxillaries	1290806						
	Seperator Motor	237329						
	Total Cement Mill 6	12047613	1,406	201,484	143	59.79		59.79
	Total Cem.Prod.CM	22968159	2,743	411173	150	55.86		55.86
16	Packing Plant (K/T)	1795669	15,521	2,006,664	129	0.89		0.89
	Packing Plant (K/T)	1565290	17,074	1010297	59	1.55		1.55
	Packing Plant (K/T)	984222	5,626	384449	68	2.56		2.56
	Line 3 power	0						
	Compressor	1585773						
	Water+ Intake well	2019718						
	CCR AC & Lab	716148						
	Total	4321639		2025832		2.13		2.13
	Generation (kwh)	0						
	Total Power	225294389						
	Power Plant(self-							
	Losses	0	0.00			17.70		17.70

Table 3a Summary of Power Consumption and Output June 2024

	Total Rawmeal *(kg/kg of clinker)*	3,113934		
	Total Clinker *(Nm^3/kg)*	1,922,426		
	Total Cement *(Mt)*	2,437,005		
	Total Dispatch *(Mt)*	3,401,410		
	Power Consumption up to Clinker Line 1 *(kWh/cI)*			52.
	Power Consumption up to Clinker Line 2 *(kWh/cI)*			52.
	Power Consumption up to Clinker Line 3 *(kWh/cI)*			52.
	Total Power Consumption Up to Clinker(Line 1,2 &3) *(kWh/cl)*			157
	Line 1 Specific Power consumption *(kwh / Cement)*			48.
	Line 2 Specific Power consumption *(kwh / Cement)*			41.
	Line 3 Specific Power consumption (kwh/ Cement)			55.
	Total Power Consumption Up to Cement (Line 1,2 &3) *(kwh /cement)*			145
	NG - Fuel Consumption Line 1*(MJ/kg)*			692
	NG - Fuel Consumption Line 2 *(MJ/kg)*			720
	A = Energy Intensity in Crusher = 8.62kWh/ton cement *B = Energy Intensity in Raw Material Mill = 107.68kWh/ton cement* *M = Ratio of conversion material to one-ton of clinker i.e Clinker factor =1.6* *C = Energy Intensity in kiln =157.06kWh/ton clinker* *N = Percent of additives = 0 (No additive)* *D = Energy Intensity in cement mill =145.68kWh/ton cement* *E = Energy Intensity for additives production = 0* *F = Energy Intensity in packing = 5.00kWh/ton cement*			

Table 4 Power Consumption and Output from process stages Line1, 2 & 3 September 2024

S/No.	DEPARTMENT	*Power Consumption (kWh)*	*Running hours*	*Production (Mt)*	*Output (TPH)*	Line I (KWh/t mat.	Line I KWh/cl	Line I KWh/cem
	CRUSHER I		2,052	1,601,1	780			
	CRUSHER II		1,423	263,418	185			
	CRUSHER III		2,194	224,247	102			
	Line 2							
	CRUSHER I		4,072	1,730,28	425			
	CRUSHER II		781	323,950	415			
	CRUSHER III		2,513	128,566	51			
	Line 3							
	CRUSHER I		20	686,344	34,180			
	CRUSHER II		17	135,725	8,127			
	CRUSHER III		12	107453	8,954			
1	Incomer 1	51307722						
2	Incomer 2	62335416						
3	Incomer 3	59873513						
4	Incomer 4	81040648						
	JENBAKER	2136000						
	AGGREKO	44161220						
	WARTSILA	47028984						
	Total Power recd.	347883503						
1	Crusher(K/T)*1.0376*1.6							
	All three crushers	2436840						
	ETS/Stacker/Recl.	2121730						
	Total	4558570	2,427.24	2,088,854	861	2.18	3.52	2.84
	Line2							
	Crusher(K/T)*1.0376*1.6							
	All three crushers	4908360						
	ETS/Stacker/Recl.	2397350						
	CRUSHER 2Total	7305710	4,420.20	2,182,799	494	3.35	5.40	4.35
	Line 3							
3	Crusher(K/T)*1.0376*1.6							
	All three crushers	584857						
	ETS/Stacker/Recl.	223563						
	CRUSHER 3 Total	808420	48.78	929,522	19,055	0.87	1.40	1.82
	Line 3 SINOMA PROJECT							
4	Rawmill 1 (K/T) * 1.6							
	Mill drive & Mill Fan	12350950						
	Seperator	2864904						
	Mill / Kiln ESP Fan	11894392						
	Mill Auxillaries	2783750						
	TOTAL Rawmill 1	29893996	4,603.00	1,899,515	413	15.74	25.41	33.02
5	Mill drive & Mill Fan	12044400						
	Compressor	2135256						
	Mill / Kiln ESP Fan	17673740						
	Mill Auxillaries	3776020						
	TOTAL Rawmill 2	35629416	4,395.86	2,156,582	491	16.52	26.68	34.66
6	Mill drive & Mill Fan	5259325						
	Compressor	2057908						
	Mill / Kiln ESP Fan	6446442						

	Mill Auxillaries	2423894						
	TOTAL Rawmill 3	16187569	1,893.71	824,614	435	19.63	31.70	41.19
7	Kiln & Cooler (K/T)							
	Kiln ID fan	7011469						
	Kiln Main drive	2490948						
	Mill Auxillaries	3551429						
	Baghouse Filter Fan	4737470						
	Cooler fans	7254068						
	Cooler Auxillaries	2048111						
	Total KILN I	27093495	5,450	1,171,277	215	23.13	23.13	18.62
	Up to Clinker Power						52.07	
8	Kiln & Cooler (K/T)							
	Kiln ID fan	7691800						
	Kiln Main drive	2154390						
	Mill Auxillaries	6177290						
	Baghouse Filter Fan	0						
	Cooler EP Vent Fan	2269120						
	Cooler fans	6728243						
	Cooler Auxillaries	2895832						
	Total KILN 2	27916675	5240	1,343,613	256	20.78	2078	16.72
	Up to Clinker Power						52.86	
9	Kiln & Cooler (K/T)							
	Kiln ID fan	2270651						
	Kiln Main drive	725409						
	Mill Auxillaries	1859709						
	Baghouse Filter Fan	0						
	Cooler EP Vent Fan	960045						
	Cooler fans	788928						
	Cooler Auxillaries	3137994						
	Total KILN 3	9742736	2354	510,960	217	19.07	19.07	15.35
	Up to Clinker Power						52.17	
10	Cement Mill 1 (K/T)							
	Mill drive	28966453						
	Filter Fan	1833178						
	Mill Auxillaries	3090127						
	Total Cement MILL I	33889758	4,609	682,269	148	49.67		49.67
11	Cement Mill 2 (K/T)							
	Mill drive	28207155						
	Filter Fan	2274414						
	Mill Auxillaries	2775460						
	Total Cement MILL 2	33257029	4579	681,927	149	48.77		48.77
	Total Cement Prod.CM 1&2	67146787	9,189	1,364,196	148	49.22		49.22
12	Cement Mill 3 (K/T)							
	Mill drive	14817770						
	Filter Fan	9714898						
	Mill Auxillaries	2600750						
	Total Cement MILL 3	27133418	4,643	660,083	142	41.11		41.11
13	Cement Mill 4 (K/T)							
		15010500						
	Filter Fan	9932699						
	Mill Auxillaries	5095210						

	Total Cement MILL 4	30038409	4,801	711,928	148	41.19		41.19
	Total Cement Prod.CM 3&4	57171827	9,444	1,372,011	145	41.67		41.67
14	Cement Mill 5 (K/T)							
	Mill drive	18536817						
	Filter Fan	1847606						
		1708530						
	Seperator Motor	303470						
	Total Cement MILL 5	22396423	2,746	425,403	155	52.65		52.65
15	Cement Mill 6 (K/T)							
	Mill drive	15384327						
	Filter Fan	1694447						
	Mill Auxillaries	2436356						
	Seperator Motor	361647						
	Total Cement MILL 6	19876777	2,215	319,669	144	62.18		62.18
	Total Cement Prod.CM 5&6	42273200	4,961	745072	150	56.74		56.74
16	Packing Plant (K/T) / 1	2463815	21,631	2728600	126	0.90		0.90
	Packing Plant (K/T) / 2	168540	23,839	1364286	57	0.12		0.12
	Packing Plant (K/T) / 3	1733379	10,249	718818	70	2.41		2.41
	Line 3 power Consumption	540700						
	Miscellaneous (cement)							
	Compressor	2500535						
	Water+ Intake well etc	2915467						
	CCR AC & Lab	1054436						
	Total	6470438		2736207		2.36		2.36
	Generation (kwh)	0						
	Total Power Consump.	339701273						
	Power Plant (self-	0						
	Losses	0				2.99		2.99

Table 4a Summary of Power Consumptions and Output September 2024

	Total Rawmeal *(kg/kg of clinker)*	4,880,711		
	Total Clinker *(Nm³/kg)*	3,025,850		
	Total Cement *(Mt)*	3,481,279		
	Total Dispatch *(Mt)*	4,811,704		
	Power Consumption up to Clinker Line 1 *(kWh/cI)*			52.07
	Power Consumption up to Clinker Line 2 *(kWh/cI)*			52.86
	Power Consumption up to Clinker Line 3 *(kWh/cI)*			52.17
	Total Power Consumption Up to Clinker(Line 1,2 &3) *(kWh/cl)*			157.1
	Line 1 Specific Power consumption *(kwh / Cement)*			49.22
	Line 2 Specific Power consumption *(kwh / Cement)*			41.67
	Line 3 Specific Power consumption *(kwh / Cement)*			56.74
	Total Power Consumption Up to Cement (Line 1,2 &3) *(kwh / Cement)*			147.63
	NG - Fuel Consumption Line 1*(MJ/kg)*			690
	NG - Fuel Consumption Line 2 *(MJ/kg)*			726
	A = Energy Intensity in Crusher = 9.01kWh/ton cement			

	B = Energy Intensity in Raw Material Mill = 108.87kWh/ton cement *M = Ratio of conversion material to one-ton of clinker i.e Clinker factor =1.6* *C = Energy Intensity in kiln = 157.1kWh/ton Clinker* *N = Percent of additives = 0 (No additive)* *D = Energy Intensity in cement mill =147.63 kWh/ton cement* *E = Energy Intensity for additives production = 0* *F = Energy Intensity in packing =3.43kWh/ton cement*	

Table 5 Power Consumption and Output from process stages Line 1,2 &3 December 2024

S.No.	**DEPARTMENT**	***Power Consumption (kWh)***	***Running hours***	***Production (Mt)***	***Output (TPH)***	**Line I (KWh/t mat.**	**Line I KWh/ cl**	**Line I KWh/ cem**
	CRUSHER I		2,530	1,902,286	752			
	CRUSHER II		1,817	324,542	179			
	CRUSHER III		2,745	271,566	99			
	Line 2							
	CRUSHER I		5,042	2,371,647	470			
	CRUSHER II		827	394,692	477			
	CRUSHER III		2,799	155,592	56			
	Line 3							
	CRUSHER I		647	1,110,373	1,717			
	CRUSHER II		643	186,268	290			
	CRUSHER III		157	172,495	1,099			
1	Incomer 1	68686564						
2	Incomer 2	79287325						
3	Incomer 3	77968175						
4	Incomer 4	98083648						
	JENBAKER	2136000						
	AGGREKO	44161220						
	WARTSILA	88303100						
	Total Power recd.	458626032						
	Line 1							
1	Crusher(K/T)*1.0376*1.							
	All three crushers	2924940						
	ETS/Stacker/Recl.	2656768						
	Total	5581708	2,988.66	2,498,394	836	2.23	3.61	2.92
	Line 2							
2	Crusher(K/T)*1.0376*1.							
	All three crushers	7030250						
	ETS/Stacker/Recl.	3201660						
	Total	10231910	5,464.96	2,921,931	536	3.50	5.66	4.58
	Line 3							
3	Crusher(K/T)*1.0376*1.							
	All three crushers	614273						
	ETS/Stacker/Recl.	397574						
	Total	1011847	1,446.65	1,469,136	1,016	0.69	1.11	1.45
	Line 3 SINOMA	3283000						
4	Rawmill 1 (K/T) * 1.6							
	Mill drive & Mill Fan	14469278						
	Seperator	3441949						

	Mill / Kiln ESP Fan	14064752						
	Mill Auxillaries	3304549						
	TOTAL Rawmill 1	35280528	5,432.87	2,242,847	413	15.73	25.39	33.18
5	Mill drive & Mill Fan	15866980						
	Compressor	2694386						
	Mill / Kiln ESP Fan	23595189						
	Mill Auxillaries	4675580						
	TOTAL Rawmill 2	46832135	5,3.0469.90	2,901,968	494	16.14	26.06	34.04
6	Mill drive & Mill Fan	8071058						
	Compressor	2539633						
	Mill / Kiln ESP Fan	10374336						
	Mill Auxillaries	3752968						
	TOTAL Rawmill 3	24738015	2,979.05	1,322,271	444	18.71	30.20	39.46
7	Kiln & Cooler (K/T)							
	Kiln ID fan	8287765						
	Kiln Main drive	2931523						
	Mill Auxillaries	4287427						
	Baghouse Filter Fan	5725268						
	Cooler fans	8577785						
	Cooler Auxillaries	2415186						
	Total KILN I	32224954	6,375	1,384,147	217	23.28	23.28	18.84
	Up to Clinker Power						52.28	
8	Kiln & Cooler (K/T)							
	Kiln ID fan	10487118						
	Kiln Main drive	2820650						
	Mill Auxillaries	8048170						
	Baghouse Filter Fan	496580						
	Cooler EP Vent Fan	2976970						
	Cooler fans	9004343						
	Cooler Auxillaries	3703842						
	Total KILN 2	37537673	7,029	1,808,146	257	20.76	20.76	16.80
	Up to Clinker Power						52.47	
9	Kiln & Cooler (K/T)							
	Kiln ID fan	3715993						
	Kiln Main drive	1227953						
	Mill Auxillaries	2770438						
	Baghouse Filter Fan	402492						
	Cooler EP Vent Fan	1372593						
	Cooler fans	1336979						
	Cooler Auxillaries	5076262						
	Total KILN 3	15902710	3,756	817,316	218	19.46	19.46	15.75
	Up to Clinker Power						50.77	
10	Cement Mill 1 (K/T)							
	Mill drive	32818970						
	Filter Fan	2082457						
	Mill Auxillaries	3403128						
	Total Cement MILL I	38304555	5,226	771,521	148	49.65		49.65
11	Cement Mill 2 (K/T)							
	Mill drive	37914953						
	Filter Fan	2988337						
	Mill Auxillaries	3823693						
	Total Cement MILL 2	44726983	6,157	924,007	150	48.41		48.41
		83031538	11,384	1,695,528	149	48.97		48.97

12	Cement Mill 3 (K/T)							
	Mill drive	18776960						
	Filter Fan	12289318						
	Mill Auxillaries	3333710						
	Total Cement MILL 3	34399988	5,839	817,401	140	42.08		42.08
13	Cement Mill 4 (K/T)							
	Mill drive	89699110						
	Filter Fan	12407339						
		6598350						
	Total Cement MILL 4	37975599	6,021	895,130	149	42.42		42.42
	Total Cement Prod.CM 3	72375587	11,860	1,712,530	144	42.26		42.26
14	Cement Mill 5 (K/T)							
	Mill drive	27880279						
	Filter Fan	2765459						
	Mill Auxillaries	2404891						
	Seperator Motor	453421						
	Total Cement MILL 5	33504050	4,093	628,284	154	53.33		53.33
15	Cement Mill 6 (K/T)							
	Mill drive	23725155						
	Filter Fan	2544412						
	Mill Auxillaries	3615486						
	Seperator Motor	491097						
	Total Cement MILL 6	30376150	3,363	507,063	151	59.91		59.91
	Total Cement Prod.CM 5	63880200	7,455	1135347	152	56.26		56.26
16	Packing Plant (K/T) / 1	3158587	27,093	3403334	126	0.93		0.93
17	Packing Plant (K/T) / 2	839646	30,541	1706513	56	0.49		0.49
18	Packing Plant (K/T) / 3	2478965	15,479	1108086	72	2.24		2.24
	Line 3 power	3019600						
	Miscellaneous							
19		3299607						
20	Water+ Intake well etc	3835103						
21	CCR AC & Lab	1382833						
	Total	8517543		3404866		2.50		2.50
	Total Power Consump.	449926146						
	Power Plant (self-	0						
	Losses	0	0.00			2.56		2.56

Table 5a Summary of Power Consumptions and Output December 2024

	Total Rawmeal *(kg/kg of clinker)*	6,467,086		
	Total Clinker *(Nm³/kg)*	4,009,609		
	Total Cement *(Mt)*	4,543,405		
	Total Dispatch *(Mt)*	6,217,933		
	Power Consumption up to Clinker Line 1 *(kWh/cI)*			52.28
	Power Consumption up to Clinker Line 2 *(kWh/cI)*			52.47
	Power Consumption up to Clinker Line 3 *(kWh/cI)*			50.77
	Total Power Consumption Up to Clinker(Line1, Line 2 & Line 3) *(kWh/cl)*			155.52
	Line 1 Specific Power consumption *(kwh / Cement)*			48.97
	Line 2 Specific Power consumption *(kwh / Cement)*			42.26

	Line 3 Specific Power consumption *(kwh / Cement)*	56.26
	Total Power Consumption Up to Cement (Line 1,Line 2 & Line 3) *(kwh /cement)*	147.49
	NG - Fuel Consumption Line 1*(MJ/kg)*	685
	NG - Fuel Consumption Line 2 *(MJ/kg)*	730
	A = Energy Intensity in Crusher =8.95kWh/ton material *B = Energy Intensity in Raw Material Mill = 106.68kWh/ton cement* *M = Ratio of conversion material to one-ton of clinker i.e Clinker factor =1.6* *C = Energy Intensity in kiln = 155.52kWh/ton cement* *N = Percent of additives = 0 (No additive)* *D = Energy Intensity in cement mill =147.49kWh/ton cement* *E = Energy Intensity for additives production = 0* *F = Energy Intensity in packing = 3.66kWh/ton cement*	

Table 6Kiln Surface Temperatures Measured in ^{O}c at 30^{o}c, Over 65 Marks Segments

	Position (Mark)	Temp (^{o}.C)	Area(m^2)	Emissivity	Constant Cov.(C)	Radiation (W/mK)	Convection (W/mK)	Total (W/mK)
Kiln Shell								
	1	112	14.33	0.95	1.2	10.5	12.5	23
	2	189	14.33	0.95	1.2	28.7	40.0	68.7
	3	161	14.33	0.95	1.2	20.9	28.4	49.3
	4	228	14.33	0.95	1.2	42.1	59.0	101.1
	5	278	14.33	0.95	1.2	64.6	87.9	152.5
	6	281	14.33	0.95	1.2	66.2	89.7	155.9
	7	278	14.33	0.95	1.2	64,6	87.9	87.9
	8	269	14.33	0.95	1.2	60.1	82.3	142.4
	9	262	14.33	0.95	1.2	56.7	108.0	164.7
	10	259	14.33	0.95	1.2	55.3	76,3	55.3
	11	246	14.33	0.95	1.2	49.5	68.8	118.3
	12	299	14.33	0.95	1.2	76.1	101.4	177.5
	13	283	14.33	0.95	1.2	67.3	91.0	158.3
	14	268	14.33	0.95	1.2	59.6	81.7	141.3
	15	288	14.33	0.95	1.2	69.9	94.2	164.1
	16	301	14.33	0.95	1.2	77.3	102.8	180.1
	17	269	14.33	0.95	1.2	60.1	82.3	142.4
	18	257	14.33	0.95	1.2	54.4	75.2	129.6
	19	236	14.33	0.95	1.2	45.3	63.3	108.6
	20	197	14.33	0.95	1.2	31.2	43.7	74.9
	21	169	14.33	0.95	1.2	23.0	31.6	54.6
	22	161	14.33	0.95	1.2	20.9	28.4	49.3
	23	213	14.33	0.95	1.2	36.6	29.5	66.1
	24	316	14.33	0.95	1.2	86.4	67.3	153.7
	25	319	14.33	0.95	1.2	88.3	43.7	132
	26	344	14.33	0.95	1.2	105.4	79.9	185.3
	27	362	14.33	0.95	1.2	119.0	88.4	207.4
	28	352	14.33	0.95	1.2	111.3	83.6	194.9
	29	346	14.33	0.95	1.2	106.7	80.8	187.5
	30	353	14.33	0.95	1.2	112.0	84.1	196.1
	31	339	14.33	0.95	1.2	101.8	77.5	179.3
	32	352	14.33	0.95	1.2	111.3	83.6	194.9
	33	346	14.33	0.95	1.2	106.7	80.8	187.5
	34	339	14.33	0.95	1.2	101.8	77.5	179.3
	35	326	14.33	0.95	1.2	92.9	71.6	164.5
	36	299	14.33	0.95	1.2	76.1	60.1	136.2
	37	287	14.33	0.95	1.2	69.4	55.6	125
	38	308	14.33	0.95	1.2	81.5	63.8	145.3
	39	290	14.33	0.95	1.2	71.0	56.4	127.4
	40	283	14.33	0.95	1.2	67.3	53.7	121
	41	189	14.33	0.95	1.2	28.7	22.7	51.4
	42	122	14.33	0.95	1.2	12.3	15.3	27.6

	43	109	14.33	0.95	1.2	9.9	11.7	21.6
	44	239	14.33	0.95	1.2	46.5	65.0	111.5
	45	232	14.33	0.95	1.2	43.7	61.2	104.9
	46	165	14.33	0.95	1.2	21.9	30.0	51.9
	47	144	14.33	0.95	1.2	16.8	22.2	39
	48	234	14.33	0.95	1.2	44.5	62.2	106.7
	49	231	14.33	0.95	1.2	43.3	60.6	103.9
	50	235	14.33	0.95	1.2	44.9	62.8	107.7
	51	224	14.33	0.95	1.2	40.6	56.9	97.5
	52	227	14.33	0.95	1.2	41.7	58.5	100.2
	53	232	14.33	0.95	1.2	43.7	61.2	104.9
	54	232	14.33	0.95	1.2	43.7	61.2	104.9
	55	230	14.33	0.95	1.2	42.9	60.1	103
	56	236	14.33	0.95	1.2	45.3	63.3	108.6
	57	236	14.33	0.95	1.2	45.3	63.3	108.6
	58	249	14.33	0.95	1.2	50.8	70.6	121.4
	59	298	14.33	0.95	1.2	75.5	100.7	176.2
	60	252	14.33	0.95	1.2	52.1	72.3	124.4
	61	231	14.33	0.95	1.2	43.3	60.6	103.9
	62	237	14.33	0.95	1.2	45.7	63.9	109.6
	63	117	14.33	0.95	1.2	11.4	13.9	25.3
	64	101	14.33	0.95	1.2	8.6	9.7	18.3
	65	92	14.33	0.95	1.2	7.2	7.7	14.9
Kiln Shell						**3595.5**	**3935.6**	**7531.1**

(1) CYCLONE 110	Point 1	40	60	0.95	1	0.34	0.24	0.58
	Point 2	37	60	0.95	1	0.27	0.19	0.47
	Point 3	48	61	0.95	1	0.06	0.05	0.11
	Point 4	46	66	0.95	1	0.06	0.05	0.11
	Point 5	40	50	0.95	1	0.05	0.03	0.08
	Point 6	42	49	0.95	1	0.05	0.04	0.09
	Point 7	54	52	0.95	1	0.08	0.06	0.14
	Point 8	48	46	0.95	1	0.07	0.05	0.12
Total						**0.98**	**0.71**	**1.70**
(2) CYCLONE 210	point 1	39	42	0.95	1	0.17	0.12	0.29
	point 2	46	44	0.95	1	0.23	0.16	0.39
	point 3	53	51	0.95	1	0.06	0.04	0.11
	point 4	45	48	0.95	1	0.06	0.05	0.11
	point 5	47	52	0.95	1	0.06	0.04	0.10
	point 6	43	43	0.95	1	0.16	0.11	0.27
	point 7	49	40	0.95	1	0.24	0.17	0.41
	point 8	41	42	0.95	1	0.02	0.02	0.04
						1.00	**0.71**	**1.72**
(3) CYCLONE 120	point 1	52	86	0.95	1	0.11	0.08	0.20
	point 2	58	81	0.95	1	0.35	0.25	0.59
	point 3	56	79	0.95	1	0.07	0.05	0.12
	point 4	62	81	0.95	1	0.29	0.21	0.50
	point 5	71	88	0.95	1	0.14	0.10	0.23
	point 6	49	89	0.95	1	0.13	0.09	0.21
	point 7	46	77	0.95	1	0.03	0.02	0.05
	point 8	44	62	0.95	1	0.02	0.01	0.03
						1.14	**0.81**	**1.93**
	point 1	58	78	0.95	1	0.06	0.04	0.10
(4) CYCLONE 220	point 2	51	70	0.95	1	0.04	0.02	0.06
	point 3	59	76	0.95	1	0.38	0.27	0.65
	point 4	154	86	0.95	1	0.06	0.04	0.10
	point 5	69	67	0.95	1	0.22	0.16	0.38
	point 6	86	89	0.95	1	0.19	0.13	0.32
	point 7	51	61	0.95	1	0.16	0.11	0.27
	point 8	52	61	0.95	1	0.18	0.13	0.30
						1.29	**0.9**	**2.19**
	point 1	51	72	0.95	1	0.10	0.07	0.16

(5) CYCLONE 130	point 2	121	74	0.95	1	0.24	0.17	0.40
	point 3	70	83	0.95	1	0.08	0.05	0.13
	point 4	66	82	0.95	1	0.06	0.04	0.10
	point 5	62	63	0.95	1	0.05	0.04	0.09
	point 6	59	103	0.95	1	0.07	0.05	0.11
	point 7	77	60	0.95	1	0.03	0.02	0.05
	point 8	56	55	0.95	1	0.55	0.34	0.89
				Sub total		**1.16**	**0.77**	**1.94**
Total						**5.58**	**3.9**	**9.5**

	Position	Temp	Area	Emissivity	Constant	Radiation	Convection	Total
	Mark	°.C	m^2		Cov.(C)	kcal/kg	kcal/kg	kcal/kg
	Point 1	127	76	0.85	1.2	0.17	0.14	0.31
	Point 2	136	87	0.85	1.2	0.22	0.18	0.41
	Point 3	119	79	0.85	1.2	0.16	0.13	0.29
	Point 4	109	87	0.85	1.2	0.15	0.12	0.27
	Point 5	132	76	0.85	1.2	0.19	0.15	0.34
	Point 6	140	77	0.85	1.2	0.21	0.17	0.38
	Point 7	135	75	0.85	1.2	0.19	0.15	0.35
TAD	Point 8	123	74	0.85	1.2	0.16	0.13	0.29
						1.44	**1.18**	**2.62**
	front 1	230	25	0.85	1	0.187	0.099	0.29
	front 2	220	22	0.85	1	0.150	0.081	0.23
	front 3	195	31	0.85	1	0.164	0.096	0.26
	front 4	205	23	0.85	1	0.135	0.077	0.21
	Right side 1	214	25	0.85	1	0.161	0.089	0.25
	Right side 2	226	25	0.85	1	0.180	0.096	0.28
	Right side 3	230	31	0.85	1	0.232	0.122	0.35
	Rightside 4	221	30	0.85	1	0.206	0.112	0.32
	Left side 1	240	25	0.85	1	0.205	0.105	0.31
	Left side 2	200	24	0.85	1	0.134	0.077	0.21
	Left side 3	199	22	0.85	1	0.122	0.070	0.19
Cooler	Left side 4	196	30	0.85	1	0.161	0.093	0.25
			313			**2.04**	**1.12**	**3.15**
	side 1	200	130	0.9	1	0.77	0.42	1.19
	side 2	250	140	0.9	1	1.33	0.62	1.95
	side 3	250	141	0.9	1	1.34	0.63	1.97
	side 4	200	254	0.9	1	1.50	0.81	2.32
	side 5	230	244.2	0.9	1	1.93	0.96	2.90
Riser	side 6	230	258.852	0.9	1	2.05	1.02	3.07
						8.92	**4.47**	**13.39**

Table 7 Cumulative Output, Power Consumption and Energy Intensity for Lines (1,2 & 3) Year 2024

	MARCH	JUNE	SEPT.	DECEMBER	TOTAL OUTPUT
Total Rawmeal *(kg/kg of clinker)*	1,398,292	3,11393	4,880,711	6,467,086	**15,860,023**
Total Clinker *(Nm³/kg)*	868,048	1,922,4	3,025,850	4,009,609	**9,825,933**
Total Cement *(Mt)*	1,228,565	2,437,0	3,481,279	4,543,405	**11,690,254**
Total Dispatch *(Mt)*	1,718,515	3,401,4	4,811,704	6,217,933	**16,149,562**
	MARCH	**JUNE**	**SEPT.**	**DECEMBER**	**TOTAL POWER CONSUMPTION**
Power Consumption up to Clinker Line 1 *(kWh/cI)*				52.28	206.66
Power Consumption up to Clinker Line 2 *(kWh/cI)*				52.47	209.78
Power Consumption up to Clinker Line 3 *(kWh/cI)*				50.77	188.16
Total Power Consumption Up to Clinker(Line 1,2 & 3) *(kWh/cl)*				**155.52**	**604.6**
Line 1 Specific Power consumption *(kwh / Cement)*				48.97	195.24
Line 2 Specific Power consumption *(kwh / Cement)*				42.26	167.63
Line 3 Specific Power consumption *(kwh / Cement)*				56.26	220.88
Total Power Consumption Up to Cement (Line 1,2 & 3) *(kwh /*				**147.49**	**583.75**
NG - Fuel Consumption Line 1*(MJ/kg)*	680	692	690	685	**2747**
NG - Fuel Consumption Line 2 *(MJ/kg)*	720	720	726	730	**2896**
ENERGY INTENSITY	**MARCH**	**JUNE**	**SEPT.**	**DECEMBER**	**TOTAL ENERGY INTENSITY**
A=Energy Intensity in Crusher (kWh/ton cement)					**32.92**
B=Energy Intensity in Raw Material Mill (kWh/ton cement)					**430.56**
M=Ratio of conversion material to one-ton of clinker i.e Clinker factor					1.6
C=Energy Intensity in kiln (kWh/ton cement)	134.92	157.06	157.1	155.52	**604.6**
N=Percent of additives = 0 (No additive)	0	0	0	0	0
D=Energy Intensity in cement mill (kWh/ton cement)	142.95	145.68	147.63	147.49	**583.75**
E=Energy Intensity for additives production = 0	0	0	0	0	0
F=Energy Intensity in packing (kWh/ton cement)	5.1	5.00	3.43	3.66	**17.19**

APPENDIX II Cooler Heat Balance (Input And Output)

Cooler Heat Balance

Plant name	BUA EDO
Date	16-08-2023
Calculations by	KBS

FLSMIDTH

Version.: 2023-06

Input:

		Flow kg/s	Flow Nm³/s	Flow kg/kg cl.	Flow Nm³/kg cl.	Temperature °C	kJ/kg K / *kJ/Nm³ K*	Reference 25 °C kJ/s	Reference 25 °C kJ/kg cl.	Reference 25 °C kcal/kg cl.	Reference ambient 29 °C kJ/s	Reference ambient 29 °C kJ/kg cl.	Reference ambient 29 °C kcal/kg cl.
Hot clinker	m_{S8}	60,88		1,060		1460	1,110	96973	1688	403,5	96792	1685,0	402,7
Cooling air (ambient)	V_{L10}	155,12	121,73		2,119	29	*1,306*	636	11	2,6	0	0,0	0,0
Cooling air (hot)	$V_{L10,Um}$	0,00	0,00		0,000	0	*1,304*	0	0	0,0	0	0,0	0,0
Power cooler fans [kW]	$P_{mech,K}$	1044	*5,05 kWh/t*					940	16,4	3,9	940	16,4	3,9
Water injection	$m_{H_2O,10}$	0,000	0,000	0,000	0,000	30	4,184	0	0,0	0,0	0	0,0	0,0
Total heat, in								98549	1716	410	97731	1701	407

Output:

		Flow kg/s	Flow Nm³/s	Flow kg/kg cl.	Flow Nm³/kg cl.	Temperature °C	kJ/kg K / *kJ/Nm³ K*	Heat kJ/s	Heat kJ/kg cl.	Heat kcal/kg cl.	Heat kJ/s	Heat kJ/kg cl.	Heat kcal/kg cl.
Secondary air	V_{L8}	36,51	28,65	*0,636*	0,499	860	*1,398*	33458	582,5	139,2	33308	579,9	138,6
- Dust	m_{St8}	1,43		0,025			0,976	1168	20,3	4,9	1164	20,3	4,8
Tertiary air (cooler)	V_{L9}	35,98	28,23	*0,626*	0,492	860	*1,398*	32968	573,9	137,2	32820	571,4	136,6
- Dust	m_{St9}	2,00		0,035			0,976	1634	28,4	6,8	1628	28,3	6,8
Hot air	V_{L13}		0,000		0,000	0	*1,304*	0	0,0	0,0	0	0,0	0,0
- Dust	m_{St13}	0,00		0,000			0,729	0	0,0	0,0	0	0,0	0,0
Vent/excess air	V_{L11}		64,844		1,129	290	*1,328*	22839	397,6	95,0	22500	391,7	93,6
- Dust	m_{St11}	0,84		0,015			0,861	193	3,4	0,8	190	3,3	0,8
Uncoupled heat cooler	$Q_{K,K}$							0	0,0	0,0	0	0,0	0,0
Clinker	m_{S10}	56,60		0,985		145	0,804	5462	95,1	22,7	5293	92,2	22,0
Tertiary air dust dumped	m_{St12}	0,00		0,000		0	0,729	0	0,0	0,0	0	0,0	0,0
Evaporation water injection	$\Delta H_{V,H_2O}$	0,00	0,000	0,000	0,000		2446	0	0,0	0,0	0	0,0	0,0
Surface loss pre-cooling zone	$Q_{W,Pre\text{-}cool}$							329	5,7	1,4	329	5,7	1,4
Surface loss cooler + kiln hood	$Q_{W,K}$							961	16,7	4,0	961	16,7	4,0
Total heat, out								99012	1724	412	98194	1709	409
Error								0,47%					

APPENDIX III Kiln Heat Balance Input and Output

Kiln Heat Balance

Plant name	BUA EDO
Date	16-08-2023
Calculations by	KBS

FLSMIDTH

Version.: 2023-06

Input:

		Flow kg/s	Flow Nm³/s	Flow kg/kg cl.	Flow Nm³/kg cl.	Temperature °C	kJ/kg K *kJ/Nm³ K*	Reference 25 °C kJ/s	kJ/kg cl.	kcal/kg cl.
Kiln feed	m_{S1}	95,34		1,660		60	0,842	2810	48,9	11,7
- Combustibles in kiln feed	$m_{C,eff,S}+m_{S,eff,S}$	0,00		0,000				0	0,0	0,0
Air	$V_{L,total}+V_{L11}+V_{L13}$		127,25			29	*1,306*	665	11,6	2,8
Cooler water injection	$m_{H_2O,10}+m_{H_2O,8+9}$	0,000		0,000		30	4,184	0	0,0	0,0
Fuel										
- Main burner	m_{B7}	1,62		0,028				79688	1387,3	331,6
- Secondary burner	m_{B3}	2,36		0,041				106948	1861,9	445,0
- Sensible enthalpy	H_B							187	3,3	0,8
Mechanical performance										
- Kiln drive [kWh]	$P_{mech,D}$	250 kWh	*1,2 kWh/t*					225	3,9	0,9
- Cooler fans [kWh]	$P_{mech,K}$	.044 kWh	*5,0 kWh/t*					940	16,4	3,9
Balance remainder								523	9	2
Total heat, in								191463	3333	797

Output:

		Flow kg/s	Flow Nm³/s	Flow kg/kg cl.	Flow Nm³/kg cl.	Temperature °C	kJ/kg K *kJ/Nm³ K*	Reference 25 °C kJ/s	kJ/kg cl.	kcal/kg cl.
Exhaust gases	V_{G1}		88,886		1,547	361	*1,500*	44813	780,1	186,5
- Dust loss	m_{St1}	5,833		0,102			1,006	1972	34,3	8,2
- CO in exhaust gases	$\Delta H_{R,CO}$		0,002		0,000		12645	31	0,5	0,1
- Evaporation of free water	$\Delta H_{V,H_2O,S}$	0,143	0,178	0,002	0,003		2446	350	6,1	1,5
Surface loss preheater	$Q_{W,V}$							6749	117,5	28,1
Surface loss calciner	$Q_{W,C}$							2884	50,2	12,0
Surface loss cooler + kiln hood	$Q_{W,K}$							961	16,7	4,0
Surface loss tertiary air duct	$Q_{W,T}$							1202	20,9	5,0
Surface loss kiln shell	$Q_{W,D}$							5845	101,8	24,3
Tertiary air dust dumped	m_{St12}	0,000		0,000		0	0,729	0	0,0	0,0
Bypass gas	V_{G5}		0,000		0,000	0	*1,301*	0	0,0	0,0
- Dust	m_{St5}	0,000		0,000			0,800	0	0,0	0,0
Reaction enthalpy of bypass dust	$\Delta H_{R,St5}$							0	0,0	0,0
Hot air	V_{L13}		0,000		0,000	0	*1,304*	0	0,0	0,0
- Dust	m_{St13}	0,000		0,000			0,729	0	0,0	0,0
Vent/excess air	V_{L11}		64,8		1,129	290	*1,328*	22839	397,6	95,0
- Dust	m_{St11}	0,843		0,015			0,861	193	3,4	0,8
Uncoupled heat cooler	$Q_{K,K}$							0	0,0	0,0
Evaporation of injected water	$\Delta H_{V,H_2O,10+H_2O,8,9}$	0,000	0,000		0,000		2446	0	0,0	0,0
Clinker	m_{S10}	57,442			1,000	145	0,804	5543	96,5	23,1
Reaction enthalpy of kiln feed	$\Delta H_{R,S}$							98604	1716,6	410,3
Total heat, out								191986	3342	799
Firing according to fuel mass flow								186636	3249	776,6
Firing according to heat balance error								187160	3258	778,7
Error								0,27%		

APPENDIX IV
Table 8Quarterly Production /Power Consumption Report March 2024

Equipment	Running Hrs(h)	Production(MT)	Power consumed(KWH)	Output (TPH)
LINE 1				
Crusher1	473	540,378		1,142
Crusher II	332	97,128		293
Crusher III	793	93,890		118
All three Crushers			693079	
ETS/Stacker/Recl.			684112	
Total	620..21	731,396	**1377191**	1,179
LINE 2				
Crusher I	1521	576,986		379
Crusher II	222	103,214		465
Crusher III	680	45,362		67
All three Crushers			1476700	
ETS/Stacker/Recl.			719570	
Total	1635.20	725,562	**2196270**	444
LINE 3				
Crusher I	6	19,226		3,452
Crusher II	6	10,919		1,960
Crusher III	1	27,927		27,927
All three Crushers			0	
ETS/Stacker/Reclaimer			0	
Total	12.14	58,072	0	4,784
Line3 SINOMA PROJECT			**982000**	
Rawmill 1	1,525.20	651,496	**9845283**	427
Rawmill 2	1,483.31	740,904	**12132226**	499
Rawmill 3	26.71	5,892	**118000**	221
Kiln 1	1,836	404,444	**9224348**	220
Kiln 2	1813	463,604	**9734897**	256
Kiln 3	0	0	**15000**	0
Cement Mill 1	1800	274,382	**13482310**	152
Cement Mill 2	1764	284,952	**12876675**	150
Cement Mill 3	1676	246,346	**10033010**	147
Cement Mill 4	1672	250,420	**10862039**	150
Cement Mill 5	1133	177,581	**8960893**	157
Cement Mill 6	166	14884	**1050738**	90
Parking plant 1	8,011	916703	**1036597**	129
Parking plant 2	8,224	778240	**501899**	61
Parking plant3	2,755	481050	**180019**	65
Compressor			775586	
Water intake Well etc			977438	
CCR,AC &Lab			356027	
Total		1036100	**2109051**	
Total power consumed			**101356006**	
Total Power received			**110828544**	
Total Power saved			**9472538**	

Table 9 Quarterly Production/Power Consumption Report June 2024

Equipment	Running Hrs	Production	Power consumed(KWH)	Output (TPH)
LINE 1				
Crusher1	1,144	1,096,237		958
Crusher II	820	175,149		214
Crusher III	1,512	171,008		113
All three Crushers			1774557	
ETS/Stacker/Recl.			1357044	
Total	1,410.65	1442394	**3131601**	1022
LINE 2				
Crusher I	3,026	1,178,862		390
Crusher II	463	206,774		447
Crusher III	1,583	95,039		60
All three Crushers			3243480	
ETS/Stacker/Recl.			1571180	
Total	3257.99	1,480,676	**4814660**	454
LINE 3				
Crusher I	6	302,563	54,320	54,320
Crusher II	6	48,459	8,700	8,700
Crusher III	1	51,883	51,883	51,883
All three Crushers			298871	
ETS/Stacker/Reclaimer			15699	
Total	12.14	402,905	**314570**	33,188
Line 3 SINOMA PROJECT			**1905000**	
Rawmill 1	3,138.90	1,292,457	**20405984**	412
Rawmill 2	3,016.71	1,493,790	**24016286**	495
Rawmill 3	755.61	327,677	**6497472**	434
Kiln 1	3,732	797,412	**18389903**	214
Kiln 2	3616	928,401	**19417467**	257
Kiln 3	969	196,613	**3853968**	203
Cement Mill 1	3,199	484,216	**23566773**	151
Cement Mill 2	3446	518,456	**24738049**	150
Cement Mill 3	3489	502,671	**20600258**	144
Cement Mill 4	3530	520,490	**22007419**	147
Cement Mill 5	1337	209,690	**10920546**	157
Cement Mill 6	1406	201,484	**12047613**	143
Parking plant 1		2006664	**1795669**	129
Parking plant 2	17,074	1010297	**1565290**	59
Parking plant3	5,626	384449	**984222**	68
Compressor			1585773	
Water+intake well etc			2019718	
CCR,AC &Lab			716148	
Total		2025832	**4321639**	
Total power consumed			**225294389**	
Total power received			**228820725**	
Total power saved			**3526336**	

Table 10 Quarterly Production/Power Consumption Report September 2024

Equipment	Running Hrs	Production	Power consumed(KWH)	Output (TPH)
LINE 1				
Crusher1	2,052	1,601,189		780
Crusher II	1,423	263,418		185
Crusher III	2,194	224,247		102
All three Crushers			2436840	
ETS/Stacker/Recl.			2121730	
Total	2,427.24	2,0838,854	**4558570**	861
LINE 2				
Crusher I	4,072	1,730,283		425
Crusher II	781	323,950		415
Crusher III	2,513	128,566		51
All three Crushers			4908360	
ETS/Stacker/Recl.			2397350	
Total	4.420.20	2,182,799	**7305710**	494
LINE 3				
Crusher I	20	686,344		34,180
Crusher II	17	135,725		8,127
Crusher III	12	107453		8,954
All three Crushers		584857		
ETS/Stacker/Reclaimer		223563		
Total	48.78	808420	**929,522**	19,055
Rawmill 1	4,603.00	1,899,515	**29893996**	413
Rawmill 2	4,395.86	2,156,582	**35629416**	491
Rawmill 3	1,893.71	824,614	**16187569**	435
Kiln 1	5,450	1,171,277	**27093495**	215
Kiln 2	5240	1,343,613	**27916675**	256
Kiln 3	2354	510,960	**9742736**	217
Cement Mill 1	4,609	682,269	**33889758**	148
Cement Mill 2	4579	681,927	**33257029**	149
Cement Mill 3	4,643	660,083	**27133418**	142
Cement Mill 4	4,801	711,928	**30038409**	148
Cement Mill 5	2,746	425,403	**22396423**	155
Cement Mill 6	2,215	319,669	**19876777**	144
Parking plant 1	21,631	2728600	**2463815**	126
Parking plant 2	23,839	1364286	**168540**	57
Parking plant3	10,249	718818	**1733379**	70
Compressor			2500535	
Water+intake well etc			2915467	
CCR,AC &Lab			1054436	
Total		2736207	**6470438**	
Total power consumed			**336685675**	
Total power Received			**347883503**	
Total power saved			**11197828**	

Table 11 Quarterly Production/Power Consumption Report December 2024

Equipment	Running (HRS)	Production (MT)	Power consumed(KWH)	Output (TPH)
LINE 1				
Crusher1	2,530	1,902,286		752
Crusher II	1,817	324,542		179
Crusher III	2,745	271,566		99
All three Crushers			2924940	
ETS/Stacker/Recl.			2656768	
Total	2,988.66	2,498,394	**5581708**	836
LINE 2				
Crusher I	5,042	2,371,647		470
Crusher II	827	394,692		477
Crusher III	2,799	155,592		56
All three Crushers			7030250	
ETS/Stacker/Recl.			3201660	
Total	5,464.96	2,921,931	**10231910**	536
LINE 3				
Crusher I	647	1,110,373		1,717
Crusher II	643	186,268		290
Crusher III	157	172,495		1,099
All three Crushers			614273	
ETS/Stacker/Reclaimer			397574	
Total	1,446.65	1,469,136	**1011847**	1,016
Line 3 SINOMA			3283000	
Rawmill 1	5,432.87	2,242,847	35280528	413
Rawmill 2	5,3.0469.90	2,901,968	46832135	494
Rawmill 3	2,979.05	1,322,271	24738015	444
Kiln 1	6,375	1,384,147	32224954	217
Kiln 2	7,029	1,808,146	37537673	257
Kiln 3	3,756	817,316	15902710	218
Cement Mill 1	5,226	771,521	38304555	148
Cement Mill 2	6,157	924,007	44726983	150
Cement Mill 3	5,839	817,401	34399988	140
Cement Mill 4	6,021	895,130	37975599	149
Cement Mill 5	4,093	628,284	33504050	154
Cement Mill 6	3,363	507,063	30376150	151
Parking plant 1	27,093	3403334	3158587	126
Parking plant 2	30,541	1706513	839646	56
Parking plant3	15,479	1108086	2478965	72
Line 3 power			3019600	
Compressor			3299607	
Water+intake well etc			3835103	
CCR,AC &Lab			1382833	
Total		3404866	8517543	
Total power consumed			**449926146**	
Total power Received			**458626032**	
Total power saved			**908552178**	

APPENDIX V

Table 12 Fuel Consumption in the Kiln Main Burner and Calciner per annual

MONTHS	GAS			HPFO			COAL (LIGNITE)		
	Kiln 1	Kiln 2	Kiln 3	Kiln 1	Kiln 2	Kiln 3	Kiln 1	Kiln 2	Kiln 3
January	11,956,850.00	8,110,493.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A
February	6,719,566.00	13,339,781.00	N/A	457,260.00	501,584.95	N/A	N/A	N/A	N/A
March	11,882,293.00	15,248,371.00	N/A	44,697.89	119,729.79	N/A	N/A	N/A	N/A
April	9,675,928.00	14,585,122.00	841,431.00	57,458.95	239,898.00	N/A	N/A	N/A	N/A
May	12,076,387.00	8,854,345.00	10,033,265.00	N/A	104,911.86	N/A	N/A	N/A	N/A
June	8,995,392.00	13,830,525.00	6,889,320.00	343,746.07	15,646.95	N/A	N/A	N/A	N/A
July	5,913,141.00	12,616,685.00	9,410,531.00	N/A	N/A	N/A	N/A	N/A	N/A
August	11,272,592.00	15,289,426.00	6,861,322.00	N/A	N/A	N/A	N/A	N/A	N/A
September	11,505,658.00	6,451,686.00	9,140,695.00	N/A	N/A	N/A	N/A	N/A	N/A
October	1,392,452.00	13,395,530.00	5,814,813.00	N/A	N/A	N/A	N/A	N/A	N/A
November	8,055,685.00	15,487,781.00	5,073,364.00	N/A	N/A	N/A	N/A	N/A	2,578.50
December	6,393,093.00	9,773,015.00	1,968,300.00	N/A	N/A	N/A	N/A	N/A	24,104.50
	105,839,037.00	146,982,760.00	56,033,041.00	903,162.92	981,771.55				26,683.00

APPENDIX VI ENERGY PARAMETERS AND INTENSITIES

Electrical Energy & Power Concepts

Term	Definition
Energy	Ability to do work
Power (Demand)	Rate at which work is done
Voltage	Electrical potential or charge
Current	Electrical flow
Power factor	Measure of real vs. reactive power
Real Power	Energy is used; work is done
Reactive Power	Energy is stored; work is not done

Energy Calculation

Energy = Power * Runtime

kWh = kW * hrs

Annual Energy (kWh/yr) = Input Power (kW) * Runtime(hrs/yr)

Notes:

kW can be taken from tables, calculated or measured with meters

Runtime can be estimated or measured with meters

Energy Indicators

The two kinds of energy indicators of the production of clinker and cement in international standards are:

MJ/kg Clinker

kWh/ton Cement (Sirchis 1989)

Energy & Demand Cost Calculations

Energy Cost

$ = Energy use/billing period (kWh) * Energy cost($/kWh)

Energy cost ($/kWh) may vary…

as usage amounts are exceeded

by time of day

by time of year

Demand Cost

$ = Peak demand/billing period (kW) * Demand cost($/kW)

Demand cost ($/kW) is based on sustained power for 15 min.

This cost may vary…

by time of day

by time of year

Nameplate Data Terms

•RPM: – Revolutions per minute, the rotational speed of the motor shaft

• Full Load Speed: – The RPM of the motor when the output torque is equal to the motors rated load

• Rated HP: – The torque the motor can apply when fully loaded

• Service Factor: – Service factor is a multiplier that indicates how much a motor can be overloaded under ideal ambient conditions.

• Enclosure types

– ODP: Open Drip Proof

– TEFC: Totally enclosed fan cooled

• Efficiency – ratio between the shaft output power and the electrical input power.

Motor Power Equations

• Using information from the nameplate, motor usage can be estimated as:

– kWh = (hp)(0.746kW/hp)(%Loaded)(hours)/Efficiency

– kWh = (FLA)(Volts)(PF)(%Loaded)(hours)(Phase^½)

• This estimate can be improved on by:

– Measuring Amps

– Measuring kW with a true power meter

– Run-time logging operation

Energy Equivalents

1000 joules (J) = 1 kilojoule (kJ)

1 kilowatt-hour (kWh) = 3,600,000 J or 3.6 MJ

Basic electricity:

Voltage :- This is what pushes electricity through a circuit – the"driving force"

Units are Volts (V)

Current: - This is what is pushed through by the voltage – the"flow"

Units are Amperes (A) ("Amps", for short)

Electrical power

When voltage and current work together to do something useful - such as turn a motor or light a lamp. *ƒ* Units are Watts

1000 Watts = 1 kilowatt (kW)

1 horsepower (HP) = 746 Watts

Calculating Power

Watts = Volts x Amps x Power Factor

VA = Volts x Amps

Power factor (PF) indicates how well the

Current and voltage are working together

Incandescent Lamps 100%

Large Motors 80-90%

Small Motors 60-75

APPENDIX V1I

To Calculate Waste Gases and Combustion Air

The calculation of waste gases and combustion air involves stoichiometry and material balance principles. The core process is to determine the theoretical (stoichiometric) air required for complete combustion and then account for any excess air used in the actual process.

1. Calculation of Neutral (Stoichiometric) Combustion Air

The theoretical or stoichiometric air is the minimum amount of air that provides enough oxygen to completely burn all combustible components (Carbon, Hydrogen, Sulfur, etc.) in the fuel, assuming no oxygen remains in the products.

Steps for Calculation (Mass Basis):

- Determine the elemental composition of the fuel: You need the weight percentages of carbon (CCC), hydrogen (HHH), sulfur (SSS), and oxygen (OOO).
- Write the balanced chemical equations for complete combustion of each element:

C+O2→CO2C plus O sub 2 right arrow CO sub 2

C+O2→CO2

2H2+O2→2H2O2 H sub 2 plus O sub 2 right arrow 2 H sub 2 O

2H2+O2→2H2O

S+O2→SO2S plus O sub 2 right arrow SO sub 2

S+O2→SO2

- Calculate the mass of oxygen required for each element per unit mass of fuel: Use the molecular weights (O2≈32 O sub 2 is approximately equal to 32

O2≈32

C≈12C is approximately equal to 12

C≈12

H2≈2H sub 2 is approximately equal to 2

H2≈2

S≈32S is approximately equal to 32

S≈32

O2O sub 2O2for CCC

: (32/12) ×cross×mass of C in fuel O2O sub 2 O2 for H2H sub 2H2

: (32/4) ×cross×mass of H2H sub 2H2 in fuel O2O sub 2O2for SSS

: (32/32) ×cross×mass of S in fuel

- Sum the total theoretical oxygen required (O2,theo O sub 2 comma theo end-sub O2,theo): Subtract any oxygen already present in the fuel itself.

O2,theo=O2 for C+O2 for H2+O2 for S−O2 in fuelO sub 2 comma theo end-sub equals O sub 2 for C plus O sub 2 for H sub 2 plus O sub 2 for S minus O sub 2 in fuelO2,theo=O2 for C+O2 for H2+O2 for S−O2 in fuel

- Calculate the theoretical mass of air: Air is approximately 23.2% oxygen by mass (or 21% by volume).

Mass of airtheo=O2,theo/0.232Mass of air sub theo end-sub equals O sub 2 comma theo end-sub / 0.232

Mass of airtheo=O2,theo/0.232

2. Calculation of Waste Gases

The products of combustion (waste gases or flue gases) depend on the fuel composition, the amount of air supplied (specifically, the excess air ratio), and the completeness of the reaction.

Steps for Calculation:

i. Determine the actual air used: In real-world applications, excess air is always supplied to ensure complete combustion. The excess air ratio (λlambdaλ) or percentage excess air is used in calculations.

Actual air supplied=Mass of airtheo×(1+Percentage excess air/100)Actual air supplied equals Mass of air sub theo end-sub cross open paren 1 plus Percentage excess air / 100 close paren

Actual air supplied=Mass of airtheo×(1+Percentage excess air/100)

ii. Calculate the composition of the waste gases: The products will include

CO2CO sub 2CO2

H2OH sub 2 O H2O(vapor),

SO2SO sub 2SO2, and the nitrogen (N2N sub 2N2) and excess oxygen (O2O sub 2O2) from the air supplied.

N2N sub 2N2in flue gas: All the nitrogen in the supplied air passes through unreacted.

O2O sub 2O2 in flue gas: The excess oxygen (actual O2O sub 2O2 supplied - theoretical O2O sub 2O2 required).

CO2CO sub 2CO2, H2OH sub 2 OH2O,

SO2SO sub 2SO2 in flue gas: Use the balanced chemical equations and the mass of the respective elements in the fuel to determine the mass of products formed.

iii. Convert mass to volume (if necessary): Use the ideal gas law or Avogadro's law to convert mass to volume at specific temperature and pressure conditions at standard conditions (0°C and 1.013 bar).

Engineering web applications and tools are available that automate these complex calculations based on the fuel's elemental analysis and the excess air ratio.

APPENDIX VIII

Thermal coefficient of conduction

The coefficient of thermal conduction (ε) is the unit rate of thermal load (kcal/m^2h^oC) that moves through a 1 meter thick plate of material, when the surface temperature difference is 1^oC.

Below is a list of thermal conductivity for some insulated materials:

Special clay (Moler): 0.20 w/(m.k)

Alumina (Chamotte): 0.32 to 1.4 W/(m·K).

Air: 0.024 W/(m.k) at 0^oC, 0.025W(m.k) at 20 ^oC & 0.034 at 100 ^oC

Kiln shell 1.50W/(m.k)

Calorific Conversion Table

To obtain?	kcal/kg	MJ/kg	Btu/lb
*multiply **kcal/kg** by*	1	4.187 x 10^{-3}	1.80
*multiply **MJ/kg** by*	238.8	1	429.9
*multiply **Btu/lb** by*	0.5556	2.326 x 10^{-3}	1

1 MJ = 0.000948 MMBTU

1 mega joule = 0.001gigajoules

To covert newton cubic meter to mega joules, multiply the volume in Nm^3 by calorific value

ABBRIVATIONS

CCR Central control room
Co_2 Carbon dioxide
CO Carbon monoxide
MMBTU Million British thermal unit
MJ Mega joules
KWh kilo watt hour
Nm^3 Newton cubic meter
NCA Neutral Combustion Air
WHR Waste Heat Recovery
HVAC Heat, Ventilation and Air Conditioning.

APPENDIX IX

Bua cement flow diagram