

ENERGY-EFFICIENT TECHNOLOGY CATALOGUE FOR INDUSTRIAL KILN AND FURNACE SYSTEM



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Vietnam Scaling Up Energy Efficiency Project (VSUEE) and Vietnam Technology Solutions Joint Stock Company (VETS).



Vietnam Scaling Up Energy Efficiency Project (VSUEE)

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FURNACE SYSTEM**

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LIST OF ABBREVIATIONS

Abbreviations	English meaning
AI	Artificial Intelligence
BEE	Bureau of Energy Efficiency
MOLISA	Ministry of Labour, Invalids and Social Affairs
CAPEX	Capital Expenditure
DAS	Data Acquisition System
DN	Enterprise/Company
DR	Demand Response
DCS	Distributed Control System
EAF	Electric Arc Kiln
EMS	Energy Management System
EVN	Viet Nam Electricity (Electricity of Viet Nam)
EU	European Union
ESCO	Energy Service Company
EPC	Engineering, Procurement and Construction Contract
U.S. DOE	United States Department of Energy
EnPI	Energy Performance Indicator
FGR	Flue Gas Recirculation
FLOX	Flameless Oxidation
G7	Group of Seven
HSE	Health, Safety and Environment
IoT	Internet of Things
IEEJ	The Institute of Energy Economics, Japan
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
JICA	Japan International Cooperation Agency
JIS	Japanese Industrial Standards
KPI	Key Performance Indicator
LPG	Liquefied Petroleum Gas
LCC	Life Cycle Cost
MPC	Model Predictive Control
MOC	Management of Change
MES	Manufacturing Execution System
MTBF	Mean Time Between Failures
MTTR	Mean Time To Repair
M&V	Measurement and Verification
NG	Natural Gas
NPV	Net Present Value

Abbreviations	English meaning
NEDO	New Energy and Industrial Technology Development Organization
OEE	Overall Equipment Effectiveness
O&M	Operation and Maintenance
PID	Proportional–Integral–Derivative (Controller)
PPE	Personal Protective Equipment
PLC	Programmable Logic Controller
Pa	Pascal
PCCC	Fire Prevention and Fighting
QA	Quality Assurance
QCVN	National Technical Regulation of Viet Nam
RDF	Refuse-Derived Fuel
RFQ	Request for Quotation
SCADA	Supervisory Control and Data Acquisition
SEC	Specific Energy Consumption
SIL	Safety Integrity Level
SOP	Standard Operating Procedure
SC	Short Circuit
SNCR	Selective Non-Catalytic Reduction
SCR	Selective Catalytic Reduction
SLA	Service Level Agreement
TKNL	Energy Efficiency/Energy Saving
TOU	Time-of-Use Tariff
TNHH	Limited Liability Company (LLC)
TCO	Total Cost of Ownership
TCVN	Vietnamese Standards
USD	United States Dollar
URS	User Requirement Specification
VSUEE	Viet Nam Scaling Up Energy Efficiency Project
VFD	Variable Frequency Drive
WHR	Waste Heat Recovery
WtE	Waste-to-Energy

FOREWORD

In the context of Vietnam's rapid industrialization, energy-intensive sectors such as cement, ceramics, metallurgy, glass, construction materials, and food processing play a vital role in driving economic growth while simultaneously exerting immense pressure on energy demand and greenhouse gas emissions. At the core of these production lines are various types of industrial kiln and furnace, from firing and incineration kilns to melting kilns, which consume a significant portion of fuel and directly determine product quality, production efficiency, and operational costs. Therefore, enhancing the energy efficiency of industrial kiln and furnace is not only a direct economic solution by reducing fuel, operation, and maintenance costs, but also a critical lever for boosting competitiveness, ensuring energy security, and achieving the emission reduction targets Vietnam has committed to.

In this context, developing a reliable reference document that can be regularly updated and accurately reflects on-site operational practices regarding high-efficiency industrial kiln technologies is an urgent necessity.

This Catalogue has been compiled under the VSUEE Project ("Vietnam Scaling Up Energy Efficiency"), supported by the World Bank and the Green Climate Fund. Its primary objective is to catalyze investment and the adoption of energy-efficient technologies and solutions within the industrial sector. The project's methodology emphasizes the development of "Technology Catalogues" to serve as a robust techno-economic foundation for investment planning, screening, and decision-making. These catalogues are built upon synthesized evidence from both domestic and international research, extensive multi-stakeholder consultations, and are designed with a strong emphasis on accessibility for industrial enterprises and financial institutions alike.

Drawing upon the methodology and experience in developing technology databases from partners, particularly the proven catalogue model successfully applied to power generation, energy storage, and renewable fuels, this catalogue aims to provide a consistent, multi round reviewed information platform. It serves to facilitate the comparison, selection, and implementation of high efficiency industrial kiln solutions tailored to Vietnam's specific conditions.

The primary objectives of this catalogue are threefold: to clarify industrial kiln and furnace technology options that deliver outstanding energy saving performance and greenhouse gas (GHG) emission reduction potential in priority

sectors; to guide enterprises in identifying energy saving opportunities throughout the equipment lifecycle; and to assist consulting and financial organizations in evaluating projects based on reliable techno economic indicators. This document deliberately avoids being an exhaustive list, instead concentrating on representative models suitable for comparison, thereby enabling users to quickly narrow down viable solutions and make informed decisions. Concurrently, the catalogue provides critical notes on operational conditions in Vietnam, covering fuel types, supply chains, after sales services, and environmental safety regulations, to ensure high applicability in practice.

The scope of this catalogue is strictly focused on industrial kiln and furnace system used in thermal processing within manufacturing enterprises and intentionally excludes boilers, thermal oil heaters, and drying ovens. These topics are or will be addressed in separate dedicated documents. This focused scope allows for in depth coverage of critical aspects of industrial kiln and furnace system, including their technological and operational characteristics, applicable temperature ranges and uses, performance and safety and environmental standards, opportunities for energy savings in design and retrofit and control, investment and payback pathways, as well as common implementation barriers and solutions within the context of Vietnamese manufacturing facilities.

The primary users of this catalogue are plant technical staff and energy managers, energy consulting and auditing firms, credit institutions and financial entities seeking viable energy efficiency projects, as well as regulatory agencies, industry associations, and training institutions. For small and medium sized enterprises (SMEs), the document emphasizes an intuitive presentation style, featuring illustrative examples, reference parameters, and key checkpoints to enable preliminary self assessment of energy saving opportunities before hiring consultants or engaging with equipment suppliers.

The editorial team extends sincere appreciation to agencies within the Ministry of Industry and Trade, domestic and international experts, industrial enterprises, technology providers, and development partners for their contributions, data verification, and sharing of practical experience throughout the compilation process. Broad participation and open dialogue among all stakeholders are essential conditions for ensuring this catalogue remains closely aligned with actual plant operations and continues to be updated and refined in line with technological progress and market demands.

This catalogue is intended to serve as a practical reference to support enterprises and stakeholders in making more informed investment decisions, reducing energy intensity and emissions, enhancing competitiveness, and contributing meaningfully to Vietnam's equitable and sustainable energy transition.

Note: Throughout this catalogue, the term "industrial kiln and furnace system" is understood to refer to kilns/incinerators/melting kilns used for the purpose of heating – processing materials within the production process. This definition excludes boilers, thermal oil heaters, and drying kilns.

CHAPTER 1. OVERVIEW OF INDUSTRIAL KILN AND FURNACE TECHNOLOGY

1.1 Technology overview

In thermal energy intensive industries such as cement, ceramics, building materials, metallurgy, glass, chemicals, textile dyeing, and food processing, industrial kiln and furnace serve as the central thermal part of the production line. Within this catalog, the term industrial kiln and furnace refers to equipment that generates, transfers, and controls heat for the purposes of firing, incinerating, melting, tempering, annealing, soaking, or heat treating materials. The scope of this document explicitly excludes boilers, thermal oil heaters, and drying kilns. In essence, an industrial kiln converts energy from fossil fuels, natural gas, biomass, electrical resistance, induction, or electric arc into thermal energy. This heat is then transferred to the material through radiation, convection, and conduction. The efficiency of this process directly determines energy consumption, production throughput, and the qualitative characteristics of the final product. Furthermore, it significantly impacts greenhouse gas emissions, operational costs, and the overall competitiveness of the enterprise.



Figure 1. Types of industrial kiln and furnace system

The critical role of industrial kiln and furnace system are evident across three primary dimensions. First, the kiln is the decisive stage that determines the microstructure and mechanical, physical, and chemical properties of the material. Even minor deviations in peak temperature, heating rate, or holding time can lead to batch product defects—impacting attributes ranging from the mechanical

strength of ceramics and the clarity of glass to the mechanical properties of heat-treated steel.

Second, the kiln and furnace typically represents the single largest consumer of energy within a plant, accounting for 30–80% of total energy demand depending on the industry. Consequently, it is invariably the primary focus of any energy-saving program.

Third, kiln and furnace are a major source of greenhouse gas emissions and local pollutants (NO_x, SO₂, CO, particulate matter) when fossil fuels are used. Therefore, advanced technological solutions for kiln and furnace carry not only economic significance but also crucial value for complying with environmental regulations and fulfilling corporate emission reduction strategies.

Industrial kiln and furnace system possess unique operational characteristics that distinguish them from other mechanical and electrical equipment. These units operate across an extensive temperature range, from medium to extreme highs. Ceramic and metal heat treatment kilns typically run at 800 to 1,200°C. Reduction and steel slab reheat kilns operate between 1,100 and 1,250°C. Glass melting kilns function from 1,400 to 1,600°C.

The operational efficiency of a kiln is determined by the design of the combustion chamber and flue gas path, the air-fuel supply system, the ability to control temperature by zone, and the quality of insulation/refractory lining.

In practice, the energy consumption and emissions of a kiln/furnace are simultaneously influenced by three main groups of factors:

- Flue gas losses (high flue gas temperature, excess air, incomplete combustion);
- Shell and leakage losses (poor insulation, degraded lining, kiln doors/gaps);
- Losses due to sub-optimal operation and control (under-load operation, unsuitable heating program, idle heating time, non-standardized maintenance).

Therefore, the approach to improving efficiency should be viewed from a system optimization perspective, combining technical solutions with operational management solutions.

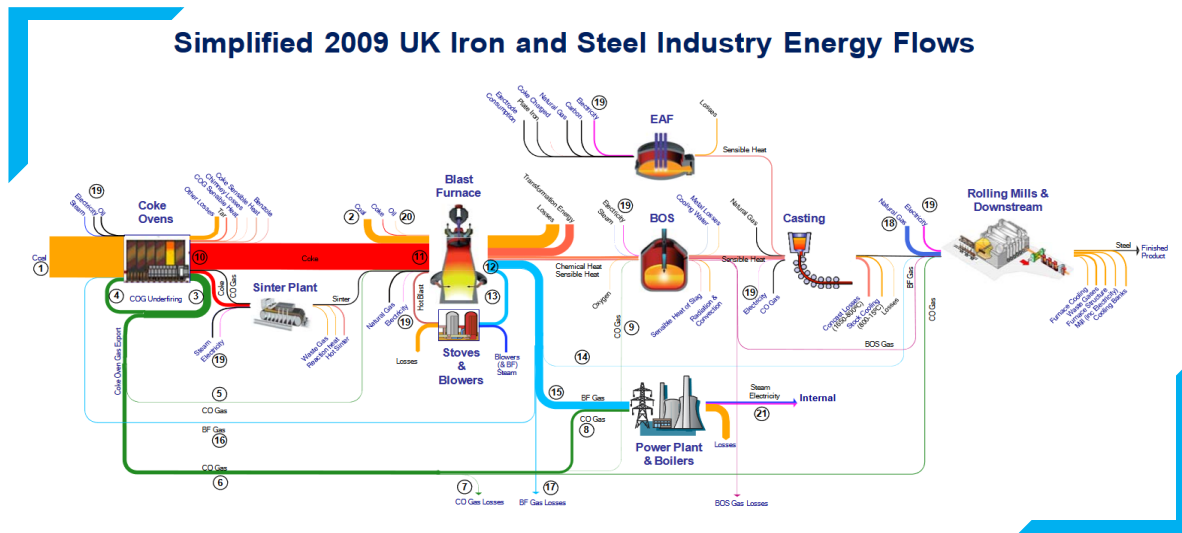


Figure 2. Energy flow diagram in a typical iron and steel production plant

In summary, industrial kiln and furnace system are both major energy consumers and quality-determining components, with diverse technological architectures and vast optimization potential. Correctly understanding the fundamentals of heat transfer and combustion, refractory and insulation structures, burner-control-heat recovery systems, and their relationship with product quality requirements is the foundation for identifying savings opportunities, designing effective investment solutions, and ensuring safe, stable operation. Subsequent sections of this manual will delve into representative kiln technology groups, their technical-economic parameters, key improvement measures, and application guidance tailored to Vietnamese enterprises, all aimed at reducing energy intensity and emissions while enhancing sustainable competitive advantage.

1.2 Technology classification

In actual production, “industrial kiln and furnace system” are a very diverse group of equipment in terms of structure, operating mechanisms, and heating methods. A reasonable classification helps readers quickly identify suitable solution groups, compare performance – costs, and guide upgrades. This section introduces common classification methods (excluding boilers, thermal oil heaters, dryers) and emphasizes the technical attributes significant for energy efficiency, product quality, and ease of implementation.

1.2.1 Classification by structure and operating mechanism

This classification is based on kiln chamber geometry, material movement, and flame/fire organization. It is the basis for understanding heat transfer characteristics, temperature uniformity potential, and optimization potential. Accordingly, kiln types include:

- » Batch/box kiln: Enclosed chambers, materials are loaded/unloaded in batches. Suitable for metal heat treatment, special ceramics, and parts with diverse sizes/cycles. Advantages include flexible operating modes; challenges are heat loss from door openings and high thermal mass loss in refractories for short cycles.
- » Shuttle kiln: A variant of batch kilns with movable carts for loading/unloading; suitable for ceramics and building materials. Can optimize door sealing and reduce heat loss during operation when performed correctly.
- » Tunnel kiln: Continuous type, materials move through heating – soaking – cooling zones; offer high output, good repeatability, and ease of waste heat recovery. Suitable for ceramics and building materials.
- » Roller hearth kiln: Materials move on heat-resistant rollers; provide even heat distribution, precise control, and are suitable for ceramic tiles, glass, and thin steel sheets.
- » Pusher kiln and walking beam kilns: Used in steel billet reheating; offer advantages in productivity, temperature uniformity, and utilizing waste heat for preheating combustion air/fuel.
- » Rotary kiln: Slowly rotating, inclined cylinders, widely used in cement, lime, and chemical processing; feature mixed heat transfer (convection, radiation, conduction) and are easily integrated with heat recovery systems.
- » Pit kilns and bell kiln: Designed for long/large components, advantageous for deep heat treatment; attention must be paid to heat loss through lids and kiln chamber pressure differentials.
- » Electric arc kiln and induction (holding/melting) kiln: Belong to the electric (non-fuel-fired) group, used for metal melting/holding; feature high energy efficiency at the material site and precise control, but require significant electrical infrastructure.

Regarding operating mode, kilns are divided into batch (intermittent), semi-continuous, and continuous. Continuous kilns generally have better thermal efficiency due to minimized heating/cooling cycles of the kiln shell and easier waste heat recovery, while batch kilns offer product flexibility but require attention to reducing losses during door openings and optimizing the cycle.

1.2.2 Classification by heat generation technology (method of heat generation and transfer)

This classification is directly linked to combustion efficiency, emissions, and the ability to utilize waste heat. Each method requires a specific burner/heat source design and control system:

- » Spray combustion (oil, gas) technology: Uses burners to create flames and a radiant/convective field within the kiln chamber. Variants include flat-flame burners for even heat distribution; low-NO_x burners with staged combustion or flue gas recirculation; oxy-fuel burners to increase radiant temperature and reduce flue gas volume (oxygen cost must be considered). Effectiveness depends heavily on the air-to-fuel ratio, excess oxygen, turbulence generation, and combustion zone arrangement.
- » Solid grate firing technology: For solid fuels such as coal, biomass, RDF. Heat is released through the burning fuel bed on the grate; efficiency is affected by particle size, moisture, under-grate air distribution, and grate type (static, mobile). Requires ash/slag handling and appropriate dust and NO_x control.
- » Fluidized bed technology for solid fuels: Wide load range, good mixing and heat transfer, stable combustion of difficult solid fuels; lower combustion temperature helps reduce NO_x, facilitating heat recovery. Requires precise design and control of fluidizing air and wear-resistant materials.
- » Electric heat generation technology:
 - Resistance/Radiant: Heating via resistive/radiant elements; precise control, clean, suitable for heat treatment, ceramics.
 - Electric arc kiln (EAF/arc kiln): Very high heat density for metal melting; requires a dust filtration system and high-power control.
 - Induction: Direct heating/melting within conductive materials; high work piece efficiency, increased heating rate, suitable for ferrous/non-ferrous metal casting/smelting.
 - Infrared/Microwave radiation (specialized applications): Selective surface/volume heating; effective when fast, thin, and uniform heating is required.

1.3 Typical configuration and auxiliary systems

A typical industrial kiln and furnace system consists of a heat generation section, a heat transfer and distribution section to the ware/products, along with

auxiliary systems to ensure stable, safe operation and compliance with environmental requirements. Structurally, a kiln/furnace typically includes the kiln chamber/firing zone, the kiln shell structure, insulation and refractory lining layers, kiln doors and loading/unloading positions, flue gas ducts, along with measurement points and actuators for control. Energy efficiency and kiln lifespan depend significantly on the design and construction quality of the refractory lining, the level of sealing (minimizing leakage), and load-following control capability.

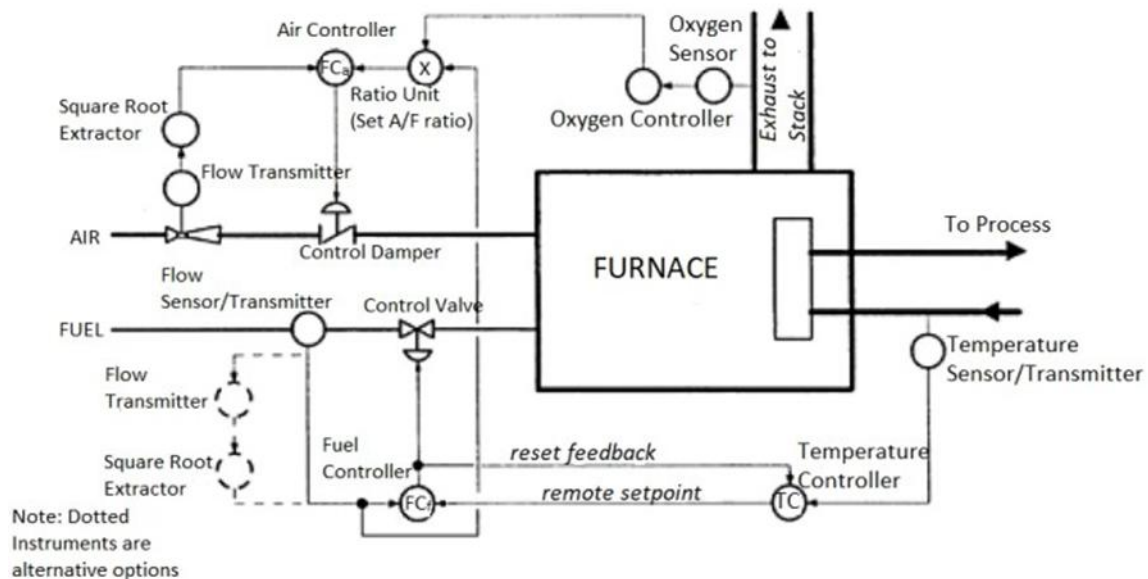


Figure 3. Typical configuration of an industrial kiln/furnace

Fuel supply system: This system ensures that fuel is received, stored, metered, and supplied to the combustion chamber in a stable and safe manner. Depending on the fuel type (coal, oil, gas, biomass, waste-derived fuel, or a combination), the configuration may include storage tanks/silos, conveying and feeding equipment, safety valves, filters, pressure regulators, flow metering devices, and protective interlocks. Core requirements are flow stability, emergency shut-off capability, prevention of leaks/fires/explosions, and fuel quality control (moisture, calorific value, impurities) to ensure stable combustion.

Combustion air and kiln ventilation system: The air system comprises fans, ducts, dampers/regulating valves, pressure and flow measuring devices, and air intake points. Its objectives are to supply an appropriate amount of air (avoiding incomplete combustion from insufficient air and reducing flue gas losses from excess air) and to ensure proper air distribution across zones. In many applications, maintaining suitable kiln chamber pressure helps reduce air leakage and improves operational stability.

Combustion system (burner/combustion chamber): The burner or combustion chamber is where the fuel-air mixing and flame/heat source formation occur. Important characteristics include: turndown ratio capability, flame stability,

flame shape adjustability, emission limits, and safety requirements (ignition, flame monitoring, automatic lockout upon failure). The choice of combustion system must suit the required temperature, product characteristics, and the kiln atmosphere.

Control, automation, and load-following integration system: The control system's task is to maintain operating parameters according to process requirements while optimizing consumption and ensuring safety. At a basic level, kilns typically have control loops for zone temperature, fuel flow, air flow, and kiln chamber pressure, accompanied by safety interlocks to prevent fire/explosion risks and equipment damage. Typical measured signals include temperature, excess oxygen levels, pressure, and flow parameters; actuators include fuel valves, air dampers, fan variable frequency drives (VFDs), and kiln door opening/closing mechanisms.

Automatic load-following capability enables the kiln to respond to production fluctuations (output increase/decrease, batch changes, raw material variations) by synchronously adjusting fuel-air ratios and heat distribution across zones, thereby reducing temperature fluctuations and limiting prolonged over-capacity or under-load operation. In highly automated kilns, control can be integrated with PLC/SCADA systems to: (i) manage the firing program (temperature ramps and holds), (ii) monitor and provide alerts for abnormalities, (iii) log data for operational analysis and improvement. Key conditions for the control system to be effective are reliable instrumentation, periodic calibration, and disciplined adherence to operating procedures.

Heat recovery system: Depending on the configuration, kilns may incorporate or be connected to equipment that recovers heat from flue gases/exhaust gases to preheat combustion air, preheat water, or support other processes. The integration of heat recovery must ensure: (i) a sufficiently stable waste heat source is available, (ii) there is a corresponding and regular demand for the recovered heat, (iii) measures are in place to control fouling/corrosion and maintain equipment cleanliness to preserve efficiency.

Flue gas treatment and stack system: This system aims to meet environmental regulations and ensure safe operation, typically consisting of the flue gas duct, dust removal equipment, gas pollution control devices (depending on fuel type), an induced-draft fan, and the stack. Beyond treatment efficiency, attention must be paid to pressure drop, corrosion risks due to the dew point, and maintenance requirements to prevent performance degradation and avoid increased energy consumption.

1.4 Advanced technology trends

Current industrial kiln technology development trends focus on dual objectives: reducing energy consumption and emissions, while simultaneously enhancing product quality stability and the level of automation. The main directions include:

Advanced combustion optimization and control: Increasing automation, implementing zone-specific and load-following control, and reducing temperature fluctuations; progressively applying advanced control techniques (such as Model Predictive Control) for large-scale kilns or those with stringent quality requirements.

System-level waste heat recovery and utilization: Expanding the recovery of flue gas heat for combustion air preheating, water heating, and drying/pre-heating processes; integrating with overall process line energy balancing to minimize "wastefully discharged heat."

Thermal material and structural upgrades: Improving insulation and refractory linings to reduce air leakage and shell heat losses; concurrently extending equipment lifespan and minimizing kiln downtime.

Energy and fuel transition: Increasing the share of electrification (full or partial), developing hybrid systems for infrastructure flexibility; expanding the use of biomass/waste-derived fuels where environmental requirements are met; preparing for low-emission fuel pathways (e.g., readiness for hydrogen) in suitable applications.

Digitalization of operation and maintenance: Enhancing instrumentation, centralized monitoring (PLC/SCADA), data logging, anomaly alerting, and procedure standardization; progressing towards condition-based maintenance and data-driven operational optimization.

1.5 Industrial applications

Depending on product characteristics, temperature requirements, and operating modes, kilns can be designed as batch or continuous, employing direct or indirect heating methods, and utilizing fossil fuels, alternative fuels, or electricity. Below are typical industrial application sectors.

Table 1. Application of industrial kiln energy efficiency technology across industrial sectors

No	Industry name	Purpose of industrial kiln application	Operating temperature range	Common configuration	Energy efficiency potential
1	Cement – Lime – Calcined Building Materials	To produce cement clinker, quicklime; requiring stable thermo-chemical reactions and uniform product quality.	900–1,450°C (clinker); 900–1,200°C (lime)	Rotary kiln with preheater tower and calciner; vertical/rotary kiln for lime.	Optimization of raw mix and feeding; waste gas heat recovery via preheater; high-efficiency burners; oxy-fuel enrichment where applicable; sealing of kiln inlet/outlet; monitoring of O ₂ /CO and fan pressure/flow balance; optimization of rotation speed, fill level, inclination.
2	Ceramics – Tiles & Bricks – Refractories	Sintering to achieve mechanical strength/glaze color; temperature-moisture profiles dictate shrinkage and surface quality.	850–1,300°C; refractories up to 1,600°C.	Tunnel (continuous) kiln, roller hearth kiln; shuttle/periodic kiln for special batches.	Preheating combustion air via heat recovery; hot gas recirculation for improved convection/heat uniformity; upgrading to high-emissivity and lightweight insulation linings; door sealing; optimization of firing-holding-cooling curves; excess air control and VFDs for fans.
3	Glass	Melting, refining, annealing; requires thermal and hydrodynamic homogeneity in the tank.	1,300–1,600°C.	Oxy-fuel or regenerative/recuperative gas-fired melting tank kiln; annealing lehr for controlled cooling.	Oxy-fuel/oxy-enriched combustion (cost-balanced); regenerative/high-quality recuperative heat recovery; batch level/convection control; high-emissivity lining; leakage reduction; thermal field monitoring via IR cameras/sensors.
4	Ferrous & Non-ferrous Metallurgy – Reheating, Melting/Holding	Reheating billets/blooms before rolling/forging; melting and holding molten metal; requires	1,000–1,250°C (reheating); 1,500–1,650°C (smelting).	Continuous reheating (pusher/walking beam/roller hearth); chamber/pit kiln; electric arc and induction kilns for melting/holding.	Combustion air preheating/regenerative heat recovery; low-emission burners; excess air and pressure balancing; VFDs for combustion/exhaust and

		minimal surface oxidation, uniform core-to-surface heating.			recirculation fans; production schedule optimization to reduce idle time; for electric kilns: load management, power factor optimization, holding zone insulation.
5	Chemicals – Advanced Materials (calcination, powder sintering, specialized heat treatment)	Precise thermo-chemical reactions, often requiring high-purity atmospheres.	300–1,600°C (process-dependent); often requires inert/reducing atmospheres or vacuum.	Small rotary tube kilns; chamber/vacuum kilns; multi-zone controlled conveyor/roller hearth kilns; electric resistance kilns for purity; induction for localized treatment.	High-quality insulation and sealing; standardized heating/cooling cycles; heat recovery for preheating feedstock or auxiliary spaces; monitoring of O ₂ /CO/H ₂ according to atmosphere requirements.
6	Other Specialized Heating Industries (Foundry, Precision Engineering, Surface Treatment...)	Annealing, tempering, surface hardening, coating... focusing on thermal precision and atmosphere control.	150–1,100°C up to ~1,200°C (some carburizing/sintering).	Chamber/bell/pit kilns; conveyor kilns for high volume; induction kilns for local hardening; many electric resistance/vacuum applications.	Multi-zone control; recirculation fans for enhanced convection; excess air control or inert atmosphere management; micro-structured insulation; cycle optimization to reduce residence time.

CHAPTER 2. ENERGY SAVING SOLUTIONS

2.1 Selection of energy saving solutions

This section provides pre-feasibility screening guidelines to help users quickly identify suitable solution groups, preliminarily estimate potential savings ranges, investment costs (CAPEX), and payback periods, while standardizing the minimum required information for internal/corporate proposals and documentation for financial institutions. The rapid screening process for energy efficiency solutions consists of 5 steps as follows:

- Step 1 – Define Context: Kiln/process type, fuel type, temperature range, production capacity, operating hours, and quality constraints.
- Step 2 – Establish Baseline: Aggregate energy consumption (by shift/month), specific energy consumption, energy costs, and key operating parameters (O₂/CO, flue gas temperature, pressure, sealing condition).
- Step 3 – Screen opportunities: Based on symptoms and quick data, identify priority solution groups (no-/low-cost first, followed by medium-to-high CAPEX items).
- Step 4 – Quick financial assessment: Apply reference savings percentage ranges to the baseline; estimate investment costs based on CAPEX ranges; calculate reference payback and perform sensitivity checks against energy prices.
- Step 5 – Finalize pre-feasibility option: Define scope, main risks, shutdown schedule, Measurement & Verification (M&V) plan, and requirements for performance guarantees from suppliers.

Accordingly, the minimum information to be collected includes but is not limited to the information in the table below:

Table 2. Minimum required information set

Information required	Suggestions for source/notes
Information about the kiln/furnace and process	Kiln/furnace type, temperature range, capacity/production output, material-energy flow diagram, annual operating hours.

Energy baseline	Fuel / electricity consumption per period; specific consumption per ton of product or per batch; energy invoices.
Key operating indicators	O ₂ / CO ratio (if applicable), flue gas temperature, fan / stack draft pressure, shell surface temperature, door / gap condition.
Quality & safety constraints	Temperature limits, temperature uniformity requirements, NO _x / CO / dust emission limits; existing safety interlocks.
Shutdown constraints	Maintenance windows, production schedule, requirements for test runs and kiln drying (if refractory repair/rebuild is involved).
Project objectives	Reduce energy costs, increase product quality stability, increase capacity, reduce CO ₂ emissions / pollution.
Investment scope & financing model	Budget, payback period requirement, capital mobilization capability, ESCO / leasing / co-financing / guarantee models.
M&V plan and performance commitment	Indicators to be measured, metering equipment, M&V methodology, and performance guarantee terms with the contractor.

After conducting a preliminary financial effectiveness assessment, proceed with a quick comparison against the reference information in Table 2 to make a rapid decision.

2.2 Energy saving solutions/technologies for industrial kiln and furnace system

From a practical standpoint, energy efficiency (EE) solutions for industrial kiln and furnace system (excluding steam boilers, thermal oil heaters, and drying ovens) revolve around a few core "pillars". The first is combustion and control optimization, including upgrading to high-efficiency/low-NO_x burners, improving air distribution, operating at optimal excess O₂ levels, and implementing multi-zone recipe-based control. This is often the "low-hanging fruit", typically reducing energy consumption by 5–15% while stabilizing product quality. The second is flue gas heat recovery using combustion air preheaters (recuperators) or regenerators, and/or fuel preheating, which significantly reduces stack losses and increases

useful thermal output. The third pillar is optimizing the lining – insulation & sealing: selecting high-emissivity refractory materials, adding lightweight insulation layers, addressing expansion joints/thermal bridges, and sealing charging/discharge doors. These measures reduce heat transfer through the shell and thermal mass losses during cycling.

Concurrently, the digitalization and monitoring of operations through sensors measuring oxygen (O₂), carbon monoxide (CO), multi-point temperature, pressure, and flow, coupled with a centralized data acquisition and monitoring system (SCADA/DAS) and data analytics, and the integration of Variable Frequency Drives (VFDs) for fans and pumps, enable data-driven management, early detection of anomalies, and the maintenance of stable long-term operational performance. At the strategic level, enterprises may consider fuel transition options such as electric resistance, induction, or arc heating; configuring hybrid electric–firing systems; co-firing biomass or waste-derived fuels; or opting for pure oxygen combustion / hydrogen-ready kilns. These choices are tied to carbon emission reduction goals and existing energy infrastructure conditions.

Integrating heat between hot and cold process stages and standardizing operation and maintenance practices complete the overall system optimization, often yielding significant additional savings with relatively low investment.

A typical implementation roadmap consists of the following steps: Standardize operations and metering → optimize the combustion process / implement automatic excess air control & VFDs → recover waste heat and improve insulation and sealing → implement advanced automation and data-driven optimization → consider fuel transition or hybrid system configuration.

Key Performance Indicators (KPIs) to be monitored include: Specific Energy Consumption (SEC), O₂/CO concentration in the flue gas, exhaust gas temperature after the kiln or heat exchanger, temperature uniformity across different kiln zones, process cycle time, and product quality yield.

2.2.1 Combustion and control optimization (Burner upgrade; combustion air distribution; automatic excess air control; automation and centralized monitoring via SCADA)

Optimized combustion and control is an effective starting point for the majority of fuel-fired kilns. The core objective is to operate a stable combustion process with sufficient energy, no excess air, a uniform temperature field, and repeatable cycles. Regarding equipment, companies often upgrade to high-efficiency, low-emission burners (low-NO_x burners), or flat-flame burners to achieve more even radiation distribution; in some applications, oxy-fuel burners can be considered to increase the radiative heat transfer fraction and reduce flue gas volume. Simultaneously, it is essential to improve the combustion chamber

geometry and air distribution, ensuring a good mixing zone, creating appropriate turbulence, and avoiding local hot spots that cause surface oxidation or product deformation. For kilns operating with multiple zones, it is advisable to reorganize the heating/soaking/equalizing zones, standardize firing recipes, and program ramp-soak profiles to proactively manage quality for each product type.

The second pillar is real-time closed-loop measurement and control. It is necessary to install in-situ oxygen probes to monitor dry O_2 in the flue gas; for processes sensitive to incomplete combustion, CO sensors should be added; concurrently, increase the density of temperature measurement points per zone. These signals are fed to an air-fuel ratio controller operating on a cross-limit principle to ensure safety during load increases/decreases. The control layer on the SCADA/PLC system performs O_2 -trim (automatic excess air control) to maintain optimal excess air levels, while also controlling kiln chamber pressure via dampers and Variable Frequency Drives (VFDs) for fans to prevent cold air infiltration from outside. For large production lines, Model Predictive Control (MPC) can be applied to coordinate power between zones, adjust conveyor/pusher speeds, and achieve thermal balance according to the actual load.

Key Performance Indicators (KPIs) to target include: dry O_2 around 2–4% for gaseous fuels, or 3–5% for oil (depending on product requirements); maintain flue gas CO <200 ppm as a safety limit; reduce flue gas temperature after the kiln/heat exchanger; maintain standard deviation of temperature within each zone within ± 5 – 10°C according to the process; and stable kiln chamber pressure. In terms of efficiency, proper air-fuel mixing and O_2 -trim alone can reduce consumption by 5–15%; optimizing air distribution and hot gas recirculation typically yields an additional 1–5%; with low- NO_x burners, NO_x emissions can be reduced by 20–50% without compromising quality. Indirect benefits include increased process repeatability, reduced scrap rates, and shorter startup times.

Typical investment costs include burners, O_2 /CO sensors, some additional thermocouples, a control cabinet, and fan VFDs when needed. For kilns with high loads and long operating hours, the payback period is typically 0.5–2.5 years, depending on fuel prices. Before any retrofit, it is advisable to establish an energy baseline for at least several weeks, record data via SCADA, and calculate the Specific Energy Consumption (SEC) per ton of qualified product for a "before and after" comparison.

The main risks to control are combustion safety and sensor reliability. If the air supply is reduced too quickly, the kiln may experience flame instability and increased CO; therefore, minimum CO and O_2 interlock thresholds must be set, and a purge cycle must be mandated upon restart. O_2 measurement errors due to

contamination or sensor drift can lead to faulty control; periodic calibration is required, along with installing filters/dust traps for sampling probes, and monitoring flue gas draft pressure to detect heat exchanger blockages early. Kiln pressure fluctuations causing cold air infiltration can be mitigated using pressure control dampers combined with VFDs for the exhaust fan, along with checking seals at doors, conveyor skirts, and joints.

The implementation roadmap should follow three steps:

- » Quick diagnosis (measure O₂/CO, flue gas temperature, temperature distribution, leaks, pressure fluctuations; establish baseline/SEC);
- » Minimal hardware improvements (burners, sensors, cross-limit interlock (between air and fuel), VFD installation, adjusting air ducts/nozzles);
- » Data-driven optimization (activating trim control systems, standardizing firing recipes for each product, monitoring KPIs on the SCADA dashboard, periodically fine-tuning O₂ targets and zone power allocation; for large lines, consider implementing Model Predictive Control).

Throughout the process, apply Management of Change (MOC) and conduct operational and safety training to ensure project effectiveness and sustainability.

Furthermore, the Technology Readiness Level (TRL – Technology Readiness Level) should be considered. The table below provides quick recommendations on the technology readiness level for the combustion and control optimization group.

Table 3. Economic - financial benefit parameters of energy-saving technology groups for industrial kiln and furnace system

Solution / Technology	Technology readiness level (TRL 1–9)	Investment / Operating cost	Availability (Market / Supplier)	Applicability in Vietnam (Prerequisites)
Air-fuel ratio tuning; excess oxygen (O ₂) trimming; cross-limit interlock between air and fuel; optimization of setpoints	9	Low / Low (typically does not increase operating costs)	Highly Available (supported by most control systems and burners)	High. Suitable for most kilns. Minimum conditions: stable excess O ₂ measurement, periodic sensor calibration, operational discipline according to procedures.
Multi-zone control; Ramp-Soak programs; Management of	8–9	Low–Medium / Low	Available (common PLC/SCADA; many system integrators)	High. Highly effective for kilns, heat treatment kilns, drying ovens. Conditions: reliable temperature sensors, standardized procedures,

operating "recipes"				and controlled authority to change operating recipes.
Data-driven operational monitoring (SCADA/data acquisition); anomaly alerts; periodic optimization based on KPIs	8–9	Low–Medium / Low	Available (many local contractors can implement)	High. Conditions: sufficient measurement points (fuel, air, temperature, excess O ₂ , etc.), data storage, and a mechanism for assigning shift/shift-based responsibilities.
Model Predictive Control (MPC) for kilns (multivariable optimization based on load and disturbances)	7–9	Medium–High / Medium (costs for software, modeling, maintenance)	Available but selective (typically through specialized suppliers/experts)	Medium–High (conditional). Suitable for large-scale kilns or processes with strict quality requirements. Key prerequisites: sufficiently good historical data, stable measurements, and resources to maintain and periodically calibrate the model.
Oxy-fuel firing (partial or full replacement of combustion air with oxygen) integrated with combustion control	8–9 (application-dependent)	High / High (oxygen cost is the dominant factor)	Available in the market, but dependent on the industry and industrial gas infrastructure	Medium (selective). Most feasible where there is a stable oxygen supply and requirements for high temperature/reduced flue gas volume. Conditions: assessment of total operating costs, oxygen safety, and the ability to optimize the integrated combustion-flue gas system.
Hydrogen-ready burners and/or low-ratio hydrogen co-firing	6–8	Medium–High / Dependent on hydrogen price	Products exist, but adoption levels vary	Low–Medium (currently), highly dependent on the hydrogen market. Conditions: stable hydrogen supply, high safety requirements, control of NO _x emissions, evaluation of materials/design to mitigate flashback risks.

Note: The specific scoring scale for TRL is presented in Appendix 1.

As a general principle, enterprises should prioritize the implementation of solutions with high TRL (8-9), low-to-medium investment costs, and wide market

availability first. Examples include: fine-tuning the air-fuel ratio, excess oxygen (O₂) control, air-fuel interlocking, multi-zone control, and standardizing operating programs. This group of solutions carries low risk, is easy to integrate, and typically delivers quick results.

High-cost technologies or those requiring advanced operational capabilities, such as Model Predictive Control (MPC), oxy-fuel firing, or hydrogen-ready burners, should only be considered when all the following minimum conditions are simultaneously met: (i) the kiln has sufficient scale/product value to offset the costs; (ii) the measurement system and operational data are stable; (iii) there is adequate maintenance capability (sensor calibration, model/algorithm updates, operator training); and (iv) for oxy-fuel/hydrogen firing, there must be a stable supply source and a comprehensive assessment of safety, emissions, and total operating costs conducted prior to investment.

In summary, combustion and control optimization serve as a performance lever yielding fast results, at moderate cost, and with manageable risk, provided safety standards are strictly adhered to. By correctly combining suitable burner selection and optimal air distribution with closed-loop automatic excess O₂ trimming control, enterprises can typically achieve the dual objectives of reducing consumption by 5-15% and stabilizing product quality. This also establishes a solid foundation for subsequent steps such as heat recovery, refractory/insulation improvements, and advanced digitalization.

2.2.2 Waste heat recovery

Waste heat recovery is a performance lever that delivers substantial and sustainable benefits for most industrial kilns. The core principle is to use the heat from exhaust gases to preheat combustion air or preheat incoming fuel, thereby reducing stack losses and lowering fuel consumption. The most common solution is the combustion air preheater, typically in the form of shell-and-tube, plate, or ceramic honeycomb recuperators. In an air preheater, hot flue gas transfers heat to the supply air, raising its temperature before it enters the burner. For process lines requiring very high air temperatures and operating at high loads, the use of a regenerator – a device that alternately stores and releases heat between two gas streams – may be considered to achieve deeper heat recovery. In some process stages, after recovering heat for the kiln air, the remaining thermal energy in the flue gas can be further utilized for fuel preheating, mold/fixture drying, or auxiliary space heating, provided safety is ensured and cross-contamination is avoided.

Regarding applicability, waste heat recovery is particularly effective for continuous kilns or batch kilns operating multiple shifts, where the exhaust gas temperature after the kiln is above 350–400°C and operating hours are long, enabling stable heat exchanger operation. For kilns with highly corrosive or dusty

flue gas, the solution remains feasible by selecting corrosion-resistant materials, designing an appropriate air recirculation system, and installing preliminary dust filtration to reduce fouling.

Key performance indicators to monitor include: the temperature of preheated air after the recuperator (typically reaching 200–450°C depending on configuration and inlet flue gas temperature), a reduction in flue gas temperature after the heat exchanger of ≥ 100 –250°C, and a clear decrease in the proportion of stack losses in the energy balance. When operating with optimized control (e.g., maintaining O₂ at target levels and balanced pressure), companies often record fuel savings of 8–25% for air preheaters and 15–35% for regenerators. In cases using oxy-fuel burners, savings can be higher due to the significant reduction in flue gas volume. Besides savings, the heat recovery process also increases the useful thermal capacity of the kiln.

Concerning costs and payback, the investment for an industrial-scale air preheater is medium to high. Depending on the material type and corrosion protection level, the typical payback period is 1–3 years for high-capacity kilns, thanks to direct fuel savings. Regenerators require more space and complex switching mechanisms, but they deliver higher air temperatures and greater recovery efficiency; their economic viability depends on operational intensity and fuel prices. To ensure long-term effectiveness, a plan for periodic cleaning and anti-fouling measures is necessary, along with monitoring the pressure drop across the heat exchanger and establishing standard operating procedures for recirculation during excessive pressure differentials.

The main risks for heat recovery systems are fouling/sooting, high-temperature corrosion, and gas stream cross-leakage. Mitigation measures include dust pre-treatment, selecting appropriate materials (heat-resistant steel, Inconel alloys, technical ceramics), designing heat transfer surfaces to minimize fouling, providing convenient access doors for cleaning, and incorporating a recirculation bypass to maintain operation during sudden pressure spikes. For flue gases containing sulfur or halogens, the dew point must be evaluated to avoid corrosive condensation in cold sections. Combustion safety must be addressed when recovering heat for the combustion air supply air, using measures such as check valves, leak detection, and interlocking with the combustion system.

Regarding market availability, the domestic market offers standard solutions for tubular/plate-type air preheaters and ceramic honeycomb cores for high-dust, high-temperature environments. For severe corrosion applications, specialized ceramic or nickel-chromium alloy materials can be procured. Companies should request detailed heat and mass balance calculations, pressure drop simulations, and lifecycle economic assessments, rather than considering only the initial

investment cost. When heat recovery is integrated with oxygen trim (Automatic Excess Air Control) and kiln pressure control, the overall efficiency often reaches targets quickly and remains stable over time.

Table 4. Quick assessment of technology readiness and applicability in Vietnam (waste heat recovery group)

Waste Heat Recovery Solution/Technology	Technology Readiness Level (TRL 1–9)	Investment / Operating Cost	Availability (Market/Supplier)	Applicability in Vietnam (Prerequisites)
Feedwater Economizer / Boiler Heat Recovery Unit (uses exhaust heat to raise feedwater temperature)	9	Medium / Low	Very Available (domestic and international suppliers)	High. Suitable for facilities with boilers and relatively continuous operation. Conditions: control of scaling, dust cleaning plan; monitor exhaust temperature after recovery to avoid dew point corrosion (especially with high sulfur/moisture fuels).
Combustion Air Preheaters (uses exhaust heat to preheat combustion air for the kiln)	8–9	Medium / Low–Medium (may increase fan power due to pressure drop)	Available	High for heating, drying, and kiln kilns with a clear combustion air system. Conditions: sufficient temperature differential, installation space, control of cross-leakage and regular dust cleaning.
Exhaust Gas – Water Heat Exchanger for producing hot water for process/domestic use	9	Medium / Low	Very Available	High if there is a stable demand for hot water (washing, pre-treatment, tank heating, etc.). Conditions: proper load matching with operating hours; control of scaling and corrosion.
Heat Recovery for Raw Material Drying/Preheating	8–9	Medium / Medium (fans,	Available	High in brick/tile, ceramics, food, building materials...

Waste Heat Recovery Solution/Technology	Technology Readiness Level (TRL 1–9)	Investment / Operating Cost	Availability (Market/Supplier)	Applicability in Vietnam (Prerequisites)
(using hot exhaust directly or indirectly via heat exchangers)		ducts, dust filters)		Conditions: compatibility with product quality (avoid contamination if using direct contact), sufficient ductwork space, dust/odor treatment solutions if needed.
Recuperators (Heat Recovery via Wall) for high-temperature kilns	8–9	Medium–High / Medium	Available, but require application-specific design	Medium–High (conditional). Suitable for kilns with high exhaust temperature and stable operation. Key conditions: suitable heat/corrosion-resistant materials; control of dust fouling; scheduled cleaning maintenance.
Regenerators (Alternating Heat Storage/Release) for large-volume, high-temperature kilns	8–9	High / Medium	Available but selective (often part of technology packages)	Medium (selective). High efficiency but requires space, complex valve/control systems, and strict maintenance discipline. Suitable for large-scale, stable-load projects.
Waste Heat to Power Generation (e.g., Waste Heat Recovery Power Generation Systems)	7–9	Very High / Medium (specialized operation & maintenance)	Available but limited (typically via specialized suppliers)	Low–Medium (selective). Only suitable when there is a large, continuous waste heat source with a sufficiently high temperature differential and attractive electricity value/operating

Waste Heat Recovery Solution/Technology	Technology Readiness Level (TRL 1–9)	Investment / Operating Cost	Availability (Market/Supplier)	Applicability in Vietnam (Prerequisites)
				hours. Conditions: space, electrical connection, operational capability, and long-term maintenance plan.
Industrial Heat Pumps utilizing Waste Heat (upgrading heat to a useful temperature)	8–9	High / Medium (electricity is the main cost)	Increasing (depending on temperature range)	Medium (conditional). Suitable when waste heat is low–medium grade but a higher temperature is needed for the process. Conditions: stable heat load, optimized electricity price and operation plan; technical and safety requirements for refrigerants and compliance with regulations.
Condensing Heat Recovery from Exhaust Gas (utilizing latent heat of water vapor in exhaust)	8–9	Medium–High / Low–Medium	Available but requires suitable materials	Medium (selective). Effective for high-moisture fuels/exhaust gases with high water vapor content and a demand for low–medium temperature hot water. Conditions: corrosion-resistant materials, condensate treatment, acid control, and stack safety.

Note: A detailed scale for the Technology Readiness Level (TRL) is provided in Appendix 1.

Enterprises should prioritize solutions with high TRL (8–9) where the application for the recovered heat is clearly defined (e.g., preheating feedwater,

combustion air, generating hot water, or drying raw materials). These solutions carry low risk and offer easily demonstrable effectiveness. Large-scale, high-investment solutions (such as waste-heat-to-power generation, large-scale regenerative heat recovery, or industrial heat pumps) should only be considered for pre-feasibility studies when the waste heat source is sufficiently large and stable. Furthermore, the thermal or electrical output generated must have a clear, regular use and demonstrable economic value to ensure the project's viability from a life-cycle cost perspective.

2.2.3 Upgrading insulation & refractory linings

Upgrading thermal insulation and refractory linings acts as a fundamental lever for all kiln types, as it directly impacts heat transfer through the shell, heat storage, and the thermo-mechanical stability of the equipment. A typical approach involves replacing or renovating the hot-face refractory layer with firebricks or refractory castables featuring high thermal emissivity, or applying high-emissivity coatings to enhance radiant heat exchange towards the load. Simultaneously, the insulation layer is augmented using ceramic fiber or ultra-insulating micro-structured materials. This work consistently includes addressing expansion joints, anchoring systems, thermal bridges, optimizing junction details, and implementing kiln door sealing (using gaskets, seals, and covers) to eliminate operational leakage of hot/cold gas.

This solution is applicable to all kilns but yields the highest benefit-to-cost ratio in batch kilns and kilns with short cycles or frequent door opening/closing, where the heat stored in the lining constitutes a significant portion of the energy consumption per batch. For continuous kilns, improved insulation significantly reduces wall heat losses and shell temperature, while allowing an increase in the operating zone temperature without exceeding permissible surface temperature limits in the surrounding workspace.

Key performance indicators to monitor post-retrofit include:

- A reduction in kiln shell surface temperature, typically by 10–30°C, depending on the initial condition.
- A decrease in wall heat loss by 15–40%, based on energy balance calculations.
- Shortened heat-up time and more stable temperature fluctuations within the target zone.

The combined result often achieves fuel savings of 3–10%, with additional savings realized when coupled with door sealing and operational optimization. Indirect benefits include increased lining lifespan, reduced downtime from cracking/spalling, and lowered safety risks from excessively hot surfaces.

From an economic perspective, investment costs are moderate, primarily comprising refractory/insulation materials, labor (demolition/installation/kiln drying), and planned downtime. The typical payback period is 1–2 years, potentially shorter for kilns with significant existing door leaks or severely degraded linings causing high losses. Companies should require detailed thermal-mechanical calculations (optimized thickness, temperature gradients across layers, thermal stress), hot spot/thermal bridge simulations, and a comprehensive kiln drying schedule to ensure post-installation quality.

Key technical risks to note include:

- Selecting materials unsuitable for the operating temperature range or chemical environment, leading to thermal shock and cracking.
- A change in radiative properties (high-emissivity coatings) potentially creating localized hot spots if burner/fan settings are not adjusted accordingly.
- Improper installation of anchors or expansion joints, causing spalling or detachment after a short period.

Mitigation measures involve a multi-layer lining design (hot face, intermediate, cold face) with properly specified anchors, strategic placement of expansion joints at deformation-prone locations, strictly controlling the heating rate according to the kiln drying procedure, and post-commissioning fine-tuning of burner air/fuel ratios or circulation fan speeds to achieve a uniform temperature field.

Regarding market availability, the domestic market offers a full range of refractory materials (bricks, castables for in-situ/pre-cast use), ceramic fiber, and microporous insulation boards, along with design, installation, and kiln drying services. High-emissivity radiant coatings are a specialized item, requiring suppliers with proven expertise in chemical and thermal compatibility, as well as application procedures. It is recommended to establish baseline data (pre- and post-project shell temperatures, wall losses, specific energy consumption) to verify performance and create a foundation for condition-based maintenance.

When implemented in synergy with door sealing, combustion chamber pressure control, and combustion optimization, upgraded insulation and refractory linings create a stable performance foundation, enabling other measures (such as waste heat recovery or automatic excess air control) to deliver their maximum potential impact.

Table 5. Quick assessment of technology readiness and applicability in Vietnam (insulation & refractory linings group)

Solution/Technology	Technology Readiness Level (TRL 1–9)	Investment Cost / Operational Cost	Availability (Market/Suppliers)	Applicability in Vietnam (with Conditions)
Sealing and reducing leakage at kiln doors, gaps, inspection windows; replacing gaskets, improving door-closing mechanisms	9	Low / Low	Very Available	Very High. Quick results if current leakage is significant. Conditions: Regular inspection, maintaining sealing mechanisms and operational discipline.
Reinforcing insulation layer on kiln shell/hot pipes; reducing thermal bridges at ribs, frames, supports	9	Low–Medium / Low	Available	High. Suitable for most kilns. Conditions: Select materials based on working temperature, protect from moisture and vibration, ensure proper installation standards.
Replacing/modifying refractory lining structure: using lightweight materials in suitable temperature zones; optimizing thickness per zone	8–9	Medium / Low	Available (requires kiln-specific design)	High (conditional). Very effective when kiln surface is abnormally hot or lining is aged. Conditions: Assess zone-specific temperatures, perform mechanical/expansion calculations, and ensure proper construction acceptance.
Using low-cement/high-durability monolithic refractory castables; optimizing anchoring and expansion joints	8–9	Medium–High / Low	Available (depends on contractor and material)	Medium–High. Suitable for areas with high thermal shock/vibration or requiring high lining durability. Conditions: Strict control of mix ratio, proper pouring–curing–drying process, rigorous quality management.
Using ceramic fiber modules/fiber insulation modules for suitable zones	8–9	Medium / Low	Available	Medium–High. Effective when reducing heat loss and increasing heating rate is needed. Conditions: Suitability for temperature, dusty/corrosive environment; mechanical protection;

Solution/Technology	Technology Readiness Level (TRL 1–9)	Investment Cost / Operational Cost	Availability (Market/Suppliers)	Applicability in Vietnam (with Conditions)
				adherence to safety protocols during installation and replacement.
Surface coating/solutions to reduce radiation and limit slag adhesion (varies by material and kiln)	7–9	Medium / Low–Medium	Available but selective	Medium (selective). Should only be applied after identifying slagging/corrosion mechanisms and with on-site testing capability. Conditions: Evaluate chemical compatibility, establish plan for periodic degradation inspection.
Monitoring lining degradation via surface temperature/thermal imaging to detect hot spots and plan repairs	8–9	Low–Medium / Low	Available	High. Suitable for all kiln types. Conditions: Standardized measurement procedures, clear warning thresholds and maintenance feedback mechanisms.

Priority should be given to implementing solutions with TRL 9, low cost, and immediate impact—such as leak sealing, enhancing insulation, and hot-spot monitoring—due to their ease of deployment and low risk. Large-scale projects involving modifications to the lining structure or refractory materials should only be decided upon after thorough on-site measurement and inspection (e.g., surface temperature/hot-spot analysis), assessment of damage causes, and finalization of construction and kiln-drying plans. This approach helps avoid risks such as cracking, spalling, and extended kiln downtime.

2.3.4 Digitalization & monitoring

Digitalization and monitoring form the foundation for data-driven operation, enabling industrial kiln and furnace system to maintain target performance and control quality in real-time. The focus is on expanding the measurement and operational control layers. At the measurement layer, install multi-point thermocouples to map zonal temperatures; oxygen probes and, when needed, CO/NO_x sensors to assess combustion; pressure, flow, and differential pressure sensors on air/flue gas ducts; and infrared cameras for flame and temperature field monitoring. All signals feed into a SCADA/DAS (Supervisory Control and Data Acquisition / Data Acquisition System) as the basis for establishing key

performance indicator (KPI) dashboards, particularly for specific energy consumption (SEC) and standard operating charts.

At the operational control layer, deploy Automatic Excess Oxygen Control, recipe-based control, and progressively apply Model Predictive Control (MPC) to optimize conveyor/car speed, power distribution between zones, and maintain stable kiln chamber pressure.

The scope of application is virtually unlimited. All fuel-fired kilns benefit, especially multi-kiln lines or high-volume production where load fluctuations and product changes are continuous. Digitalization shifts the enterprise from reactive checks to proactive monitoring with early warnings, enabling immediate decisions and reducing reliance on individual operator experience.

Target effectiveness indicators include: a declining trend in specific energy consumption over time due to operational optimization; reduced temperature deviation between kiln zones (standard deviation within permissible technological limits); and a minimum 20–30% reduction in unplanned downtime thanks to early warning systems for process disturbances (combustion anomalies, gas leaks, fouled heat exchangers, chamber pressure deviations). Additionally, it is crucial to incorporate technology-focused metrics such as product yield, cycle time, and Overall Equipment Effectiveness (OEE) to directly link energy, quality, and productivity.

Quantifiable benefits typically yield 3–10% savings in fuel/electricity from setpoint optimization, O₂ trimming, and fan speed control via Variable Frequency Drives (VFDs), excluding gains in product quality and batch traceability. For high-load kilns, an O₂ monitoring package combined with automatic excess air control and VFDs often has a payback period of <1 year; expanding to SCADA + data analytics typically achieves payback in 1–2 years through reduced downtime and minimized parasitic losses.

The primary risks involve noisy or insufficient data and resistance to change. Mitigation measures include sensor standardization (placement, measurement range, thermal/corrosion protection), establishing calibration schedules and cross-checking protocols; designing a consistent data architecture (sampling frequency, data labeling, storage); and implementing Standard Operating Procedure (SOP) training to link data to concrete actions. For infrared cameras and gas sensors, assess environmental conditions (dust, radiation, vibration, high temperature) and implement protective measures (cooling, clean air purging, sight tubes).

A recommended implementation roadmap follows three stages:

(1) *Critical measurement:* Equip excess oxygen (O₂) probes, supplement with additional temperature, pressure, and differential pressure measurement

points; simultaneously activate Automatic Excess Oxygen Control and implement VFDs for forced draft/induced draft fans.

(2) *Build data foundation*: Deploy a centralized SCADA/DAS, develop KPI dashboards, and establish baseline SEC and standard operating charts for each product type.

(3) *Advanced optimization*: Analyze historical data to identify optimal setpoints, establish early anomaly alerts, and progressively pilot Model Predictive Control (MPC) for sensitive operational zones.

This approach helps “lock in” efficiency gains achieved from burner upgrades, heat recovery, and insulation projects while building sustainable data-driven operational capabilities for the plant.

2.3.5 Fuel switching

Fuel switching is a strategic lever for directly reducing emissions and raising the environmental standards of industrial kiln and furnace system, while also creating flexibility margins against energy price volatility. The core solution portfolio comprises: electrification via resistance/radiant heating, induction, or electric arc; hybrid systems combining electricity and combustion; co-firing of biomass/waste-derived fuels; and hydrogen-ready burners. In principle, electrification converts electrical energy into heat precisely at the point of need, eliminating combustion losses and local emissions; hybrid systems allow for “blending” heat sources based on load and cost targets; co-firing leverages locally available renewable fuels to lower carbon intensity; and hydrogen-ready burners enable the option for partial or complete replacement of natural gas once an H₂ supply becomes available.

The applicability scope of energy conversion solutions depends heavily on product quality requirements and the specific energy infrastructure of each facility. Localized heating, precision heat treatment, and surface treatment processes are typically well-suited for resistance or induction heating due to their precise control, clean environment, and high repeatability. Metal melting and holding stages can utilize induction or electric arc heating, depending on scale and output. For high-capacity calcining, sintering, and reduction processes (e.g., clinker or lime production), a more practical solution is co-firing biomass or refuse-derived fuel (RDF), combined with a roadmap to gradually increase the fuel substitution rate and improve burner characteristics and combustion aerodynamics. For hydrogen, the most immediate suitable application is blending H₂ at low to medium percentages into the existing fuel gas stream, concurrently with upgrading to hydrogen-ready burners, gas supply systems, and specific safety requirements.

Regarding target indicators, conversion solutions can reduce direct CO₂ emissions by 20–100%, depending on the implementation pathway:

- Electrification eliminates on-site emissions.

- Biomass/RDF co-firing reduces emissions proportionally to the fuel substitution rate.
- Hydrogen generates almost no CO₂ at the point of combustion.

Nitrogen oxide (NO_x) emissions are typically significantly reduced with electrification. For hydrogen, NO_x reduction strategies such as staged combustion or flue gas recirculation must be applied to control peak flame temperature. For some processes, induction heating can increase heating rates due to high power density, shortening cycles and reducing base load losses. Key performance indicators to monitor include: specific energy consumption, electrical power factor, fuel substitution rate (% biomass/RDF/H₂), NO_x emissions, and product quality stability.

The economic assessment is case-specific. Investment costs for electrification or hybrid electric–combustion systems are typically high to very high due to requirements for electrical elements, power cabinets, cooling systems, and grid upgrades. Operational costs strongly depend on the electricity-to-fuel price correlation and the ability to schedule loads via an energy management system to avoid peak price periods. Biomass/RDF co-firing has medium investment costs (primarily for burner retrofits and feeding systems) but demands a stable fuel supply chain, especially concerning moisture and composition. For hydrogen, given supply and cost limitations, the current reasonable approach is the hydrogen-ready burner: standardizing materials, nozzles, valves, and safety interlocks from the design or retrofit phase to be ready to increase the hydrogen ratio when market conditions permit. Economic evaluation should be based on lifecycle cost, including investment, energy, maintenance, downtime, and carbon costs (if applicable).

Risk management is mandatory. Refractory materials must be validated for compatibility with the new thermal spectrum and gas environment (hydrogen has a fast flame propagation speed and high diffusivity; biomass/RDF ash and alkalis cause fouling and corrosion). For hydrogen, a comprehensive explosion safety assessment must be conducted, including leak detection, forced ventilation, safety valves, purging, safety interlocks achieving the required Safety Integrity Level (SIL), and personnel training. For electrification, risks shift to electro-thermal aspects, requiring arc flash protection, cooling control, harmonic filtering, and power limitations; thus, it necessitates integration with an energy management system and operational planning according to electricity tariffs. Co-firing requires fuel quality control (particle size, moisture, chlorine/sulfur content) and the selection of appropriate dust filtration and corrosion protection solutions to safeguard equipment, especially heat recovery systems.

Regarding technology readiness levels: Induction and electric arc are widely applied in metallurgy. Resistance/radiant heating is ready for heat treatment and technical ceramics. Biomass/RDF co-firing has been commercially deployed in many plants. Hydrogen-ready burners are available on the market, although the hydrogen supply remains limited. The recommended roadmap consists of:

- (1) Technical, quality, and safety assessment;
- (2) Simulation of energy balance and electrical load;
- (3) Lifecycle cost analysis and energy/carbon price scenarios;
- (4) Small-scale pilot, followed by expansion according to approved emission reduction milestones and cost ceilings.

This approach enables controlled decarbonization for enterprises, avoids production disruption, and optimizes investment effectiveness stage by stage.

Table 6. Rapid assessment of technology development and applicability in Vietnam (fuel switching group)

Technology/ Solution	Technology Readiness Level (TRL 1-9)	Capital Expenditure (CAPEX) / Operational Expenditure (OPEX)	Market & Supplier Availability	Applicability in Vietnam (Key Conditions)
Electrification via resistance/radiant heating elements (partial or full replacement of fuel firing)	8-9	Medium-High / Electricity price-dependent (cost often rises with high electricity prices, but combustion maintenance costs decrease)	Readily available	Medium-High (selective). Suitable for drying ovens, heat treatment furnaces, some medium-scale heating furnaces. Conditions: Sufficient electrical capacity and grid infrastructure; assessment of operating temperature limits, heating element materials, and operational costs during peak electricity periods.
Electrification via induction heating (direct heating of conductive materials)	9	High / Medium (high efficiency, but electricity price-dependent)	Readily available (multiple suppliers)	High for suitable applications (metal melting/refining, billet heating, high-frequency hardening...). Conditions: Product material and geometry must be suitable; requires cooling systems, electrical safety measures, and electromagnetic shielding.
Hybrid electric-fuel systems (partial electrification, retaining burners for peak temperature/load)	8-9	Medium-High / Dependent on operational strategy	Available, typically as integrated solutions	High (demonstrated successful implementation). Suitable where operational flexibility is needed based on energy prices/load demands. Conditions: Clear operational strategy (defining when to use

Technology/ Solution	Technology Readiness Level (TRL 1-9)	Capital Expenditure (CAPEX) / Operational Expenditure (OPEX)	Market & Supplier Availability	Applicability in Vietnam (Key Conditions)
				electric vs. fuel), upgraded interlocking controls and safety systems.
Conversion to dedicated biomass firing (rice husk, sawdust, pellets... using dedicated biomass burners/boilers)	8-9	Medium / Medium (fuel cost + logistics + ash handling)	Readily available	Medium-High (conditional). Feasible with a stable, local biomass supply. Conditions: Moisture and particle size control; ash handling/disposal; dust/emissions control; adequate storage space and fire safety provisions.
Utilization of Refuse-Derived Fuel (RDF) in suitable furnaces/combustion systems	7-9	Medium-High / Medium (dependent on RDF quality and environmental treatment costs)	Available but supply chain maturity varies	Medium (selective). Suitable for facilities with large thermal demands and robust flue gas treatment systems. Key conditions: Stable RDF quality (calorific value, chlorine, moisture content); emissions and corrosion management; compliance with environmental and co-processing regulations.
Co-firing (blending alternative fuels like biomass/RDF with primary fuel: coal/oil/gas)	8-9	Medium / Medium	Readily available	High, provided fuel quality is well-controlled. An effective transitional step when full conversion is not yet feasible. Conditions: Appropriate feeder design; stable flame control; emissions monitoring; fuel input quality control procedures.
Hydrogen-ready burners (designed for future switch to hydrogen or specific hydrogen blending)	6-8	Medium-High / Hydrogen price-dependent	Products exist, but deployment is selective	Low-Medium (currently), expected to increase as the hydrogen market matures. Conditions: Stable hydrogen supply; stringent safety requirements; NOx control; assessment of flashback, leakage, and pipeline/fitting material compatibility risks.
Low-percentage hydrogen co-firing (blending hydrogen into gaseous fuel stream)	6-8	Medium / High (due to typically high current hydrogen costs)	Selective/niche availability	Low-Medium (pilot/specialized applications). Should only be considered with on-site hydrogen availability (by-product/from other

Technology/ Solution	Technology Readiness Level (TRL 1-9)	Capital Expenditure (CAPEX) / Operational Expenditure (OPEX)	Market & Supplier Availability	Applicability in Vietnam (Key Conditions)
				processes) and comprehensive safety systems in place; requires emissions control and combustion stability measures.

A phased approach to fuel switching should be prioritized. Initiatives should begin with co-firing or hybrid electric-fuel systems when supply chains or infrastructure capacity are uncertain, as these offer lower risk and greater operational flexibility. Full electrification, large-scale RDF utilization, or hydrogen-ready projects should only be moved into the pre-feasibility portfolio once the supply infrastructure (electricity/fuel), safety-environmental plans, and operational cost analysis based on Total Cost of Ownership (TCO) are confirmed.

2.3.6 Heat integration & energy balance

Heat integration is a strategic approach to utilize surplus heat within a production line to reduce the primary load on kilns, thereby enhancing the overall plant efficiency. The principle involves using kiln exhaust gases, after primary heat recovery, to preheat raw materials, dry molds/pipelines, provide space heating, or supply adjacent process stages with a suitable temperature level. This is done concurrently with optimizing the energy balance between hot and cold process stages, and fine-tuning the entire line's pressure and air/flue gas flow rates. This approach does not involve deep intervention into the core kiln technology but creates synergistic benefits, especially in plants with multiple proximate thermal loads, short piping runs, and sufficient temperature differentials for efficient heat transfer.

Key performance indicators include a 5–15% reduction in the main kiln's thermal load, increased overall line efficiency, lower final exhaust gas temperature, and reduced auxiliary power consumption through the operation of fans at their optimal efficiency points. Additional benefits include improved working conditions (more stable workshop temperatures), reduced localized hot spots, and fewer kiln door openings due to effective preheating and heat retention strategies.

From an economic perspective, initial investment costs are moderate, primarily covering standard heat exchangers, ductwork/piping, control valves, bypass lines, insulation, and control systems. When existing infrastructure can be leveraged, a typical payback period is 1–2 years. Key risks include cross-contamination and corrosion in gas-to-gas or gas-to-liquid heat exchange.

Therefore, suitable material selection (e.g., heat-resistant steel, nickel alloys, or ceramics), segregation of sensitive streams, installation of bypasses to maintain operation during pressure drop increases, and control of acid condensation by maintaining minimum temperatures in colder sections of the system are essential.

Regarding technology readiness, most plants can implement these solutions using standard equipment integrated with existing air/flue gas ducting, combined with a centralized supervisory control and data acquisition (SCADA) system for real-time energy balance monitoring.

Table 7. Preliminary assessment of development and deployment potential in Vietnam (heat integration & energy balance solutions group)

Technology/ Solution	Technology Readiness Level (TRL 1-9)	Capital Expenditure (CAPEX) / Operational Expenditure (OPEX)	Market & Supplier Availability	Applicability in Vietnam (Key Conditions)
Establishing energy balance for kilns and production lines (identifying "major energy consumers", exhaust, shell, leakage, cooling losses...)	9	Low / Low	Very high (can be performed in-house or via consultants)	Very High. Conditions: Availability of reliable measurement/recording data (fuel, air, temperatures, production output, operating hours).
Optimizing operational modes based on load and production schedule (reducing part-load operation, minimizing warm-up/idle time, optimizing firing/drying schedules)	9	Low / Low	Very high	High. Dependent on operational discipline and production-maintenance coordination. Conditions: Established procedures, authority to adjust setpoints, and tracking of consumption metrics per shift.
Optimizing thermal distribution networks (steam/hot water/hot gas): shortening lines, reducing losses, optimizing distribution	9	Low–Medium / Low	High	High. Conditions: Site survey of current state, addressing leaks and improving pipe insulation, maintaining steam traps/valves.

Technology/ Solution	Technology Readiness Level (TRL 1-9)	Capital Expenditure (CAPEX) / Operational Expenditure (OPEX)	Market & Supplier Availability	Applicability in Vietnam (Key Conditions)
pressure & temperature				
Enhancing heat exchange between hot and cold streams within the process line (reconfiguring/adding heat exchangers)	8–9	Medium / Low	High	Medium–High (conditional). Key condition: Availability of suitable hot and cold streams in terms of temperature and flow rate; sufficient space for installation; and ability to schedule downtime for implementation.
Optimizing the "heat exchanger network" using pinch analysis methods (determining minimum heating/cooling requirements, identifying priority recovery points)	7–9	Low–Medium / Low	Available (typically via specialized consultancies/engineering firms)	Medium. Highly effective for multi-stage plants, but requires accurate data and cross-departmental collaboration.
Thermal energy storage (utilizing waste heat over time, reducing phase mismatch between heat availability and demand)	7–9	Medium–High / Low–Medium	Available but selective	Medium (selective). Suitable for batch operations or where significant timing mismatch exists between waste heat generation and its potential use. Conditions: Available space, suitable storage materials, and safety assessment.
Industrial heat pumps for upgrading low-grade heat (integrated with plant-wide energy balancing)	8–9	High / Medium (primarily electricity cost)	Growing	Medium (conditional). Suitable for sites with significant low-temperature waste heat but medium-grade heat demand. Conditions: Stable thermal loads, economic feasibility calculation based on

Technology/ Solution	Technology Readiness Level (TRL 1-9)	Capital Expenditure (CAPEX) / Operational Expenditure (OPEX)	Market & Supplier Availability	Applicability in Vietnam (Key Conditions)
				electricity tariffs and operational strategy.

Priority should be given to establishing an energy balance and optimizing operations based on load and production schedules first, due to their low cost, low risk, and their role in creating a clear "roadmap of opportunities" for all subsequent solutions. Medium-to-high investment thermal integration retrofit projects (such as adding heat exchangers, thermal storage, or industrial heat pumps) should only be implemented once suitable hot and cold streams have been identified, projected savings are clear, and downtime/construction conditions are feasible. They must also be evaluated on a Total Cost of Ownership (TCO) basis to mitigate the risk of underutilized capacity after investment.

2.3.7 Standardized operation & maintenance (O&M)

Standardized operation and maintenance serve as the foundation ensuring that the efficiency gains from technical projects are sustained over time. The focus is on developing and enforcing Standard Operating Procedures (SOPs) for material loading/unloading, door operation, soot-blowing regimes, and load changes; implementing Preventive Maintenance (PM) for burners, nozzles, fuel pumps, fans, air preheater cleaning, and periodic gas-tightness checks; and providing certified operation and combustion safety training. The goal is to increase operational stability, reduce unplanned downtime, maintain kiln shell temperatures within permissible limits, and minimize gas leakage to near zero.

Regarding performance indicators, these management and procedural solutions typically yield energy savings of 2–6% with little to no capital investment. They also extend the lifespan of refractories, burners, and fans, and reduce operational safety risks. Implementation costs are very low, primarily covering personnel training, spare parts, and basic monitoring/inspection tools.

The greatest risk lies in the lack of operational discipline and insufficient spare parts inventory. Mitigation measures include periodic training, skills assessment, transparent incentive/penalty systems, internal audits based on checklists, and developing an optimized spare parts inventory plan based on Mean Time Between Failure (MTBF) and Mean Time To Repair (MTTR) data. By integrating standardized procedures into the Supervisory Control and Data Acquisition / Data Acquisition System (SCADA/DAS) through electronic logs,

threshold alerts, and digital work orders, enterprises can establish a continuous improvement loop. This ensures industrial kiln and furnace system operate near their design efficiency points and remain ready for subsequent upgrade steps.

Technology/ Solution	Technology Readiness Level (TRL 1-9)	Capital Expenditure (CAPEX) / Operational Expenditure (OPEX)	Market & Resource Availability	Applicability in Vietnam (Key Conditions)
Developing and implementing Standard Operating Procedures (SOPs); shift-based checklists (start-up/shutdown, load change, safety checks)	9	Low / Low	Very high (can be developed in-house or via consultants)	Very High. Conditions: Clear delegation of authority, training, and monitoring for compliance; updates based on equipment/process changes.
Standardizing combustion regimes and conducting periodic tuning (excess oxygen control, flame stability, reducing excess air)	9	Low–Medium / Low	High (can be done in-house or by suppliers)	High. Conditions: Minimum measurement points (excess O ₂ /temp/pressure), sensor calibration schedule, and tracking records.
Planned preventive maintenance (heat exchanger cleaning, leak repair, gasket replacement, kiln door inspection, fan/ductwork checks)	9	Low–Medium / Medium (increased labor cost but reduced downtime)	Very high	Very High. Conditions: Risk-based planning, spare parts inventory, clear responsibility assignment, and post-maintenance evaluation.
Condition-based maintenance (based on vibration, bearing temperature, filter differential pressure, kiln surface temperature...)	8–9	Medium / Low–Medium	High (measurement equipment and services are common)	High (conditional). Conditions: Correct parameter selection per equipment, establishing alert thresholds, and clear response procedures.
Predictive maintenance (based on	7–9	Medium–High / Medium	Available but selective	Medium. Suitable for plants with good data maturity and an advanced maintenance

Technology/ Solution	Technology Readiness Level (TRL 1-9)	Capital Expenditure (CAPEX) / Operational Expenditure (OPEX)	Market & Resource Availability	Applicability in Vietnam (Key Conditions)
historical data and trend analysis)				organization. Conditions: Sufficient historical data, standardized failure codes, and analytical capabilities for continuous improvement.
Energy management via KPIs (specific consumption per shift/product; tracking dashboards and periodic review meetings)	9	Low / Low	Very high	High. Conditions: Minimum and standardized measurement/calculation methods; responsibility linked to shifts with a reasonable reward/penalty mechanism.
Operation & safety competency training and assessment (periodic, job-role specific)	9	Low– Medium / Low	Very high	Very High. Conditions: Training materials specific to the kiln technology, testing protocols, and on-site supervision.
Digitalization of operation & maintenance logs (PLC/SCADA/data logging) for root cause analysis and optimization	8–9	Medium / Low	High	High (conditional). Conditions: Standardized measurement points, data access protocols, and established procedures for using data in operational/maintenance decisions.

Priority should be given to implementing TRL 9, low-cost content such as Standard Operating Procedures (SOPs), shift-based checklists, periodic combustion tuning, and preventive maintenance first. These elements form the "foundational layer" that delivers immediate loss reduction and sustains long-term effectiveness. Advanced data-driven initiatives (Condition-based Maintenance, Predictive Maintenance, log digitalization) should only be expanded once the plant has stabilized its measurement system, standardized data practices, and established a clear response mechanism to convert alerts into action, thereby avoiding investments in systems that fail to deliver effective utilization.

2.3 Benefits of energy-saving technology

Implementing energy-saving solutions for industrial kiln and furnace system (excluding steam boilers, thermal oil heaters, and drying ovens) creates multi-dimensional value: technical-operational, economic-financial, and environmental-social. The benefits stem not only from direct fuel reduction but also from improved product quality stability, increased equipment availability, and enhanced ability to meet increasingly stringent compliance standards.

Technical & operational benefits

From a technical and operational perspective, energy-saving solutions for industrial kiln and furnace system create a chain of interconnected, compounding benefits over time.

Improved thermal efficiency: By optimizing combustion, trimming excess air, recovering waste heat for combustion air, and enhancing insulation/refractory linings, losses through exhaust gases, kiln walls, and leaks are significantly reduced. This increases the temperature of combustion air, improves the gas-tightness of the kiln chamber, and stabilizes the temperature field across zones. Energy is directed to where it's needed and utilized beneficially instead of being lost to the environment. As a result, the kiln operates more "lightly" at the same output, reducing stress on fan and flue gas systems while creating a thermal safety margin for surrounding structural components.

Stabilized and repeatable product quality: With better control over temperature across time and space within the kiln, local hot spots are minimized, reducing product surface oxidation or soot deposition. Thermal-chemical reactions occur within the optimal process window. Firing curves are maintained as designed, with more uniform core-to-surface temperatures, leading to higher yield rates and reduced scrap or rework. This is particularly critical for sensitive processes like ceramic firing, metal heat treatment, billet preheating for rolling/forging, or glass melting, where minor temperature field deviations can lead to significant quality losses.

Enhanced production capacity: Capacity improves in two ways. First, heating times and cycle times are shortened due to reduced heat storage in linings, optimized heat distribution, and standardized operational recipes. Second, for the same energy input, useful efficiency and output increase when the input zone temperature is stabilized, preventing "thermal bottlenecks" caused by excessively hot exhaust gases. Flexibility in switching between products, thicknesses, or loads also improves, as the kiln features more independent control zones, data-managed setpoints, and digitized firing recipes.

Increased equipment reliability: Cooler kiln shells and well-calculated, controlled temperature gradients across refractory linings reduce thermal stress, extending lining and anchoring system lifespan. Burners operate in their optimal range with less soot buildup and flame distortion. Air preheaters, managed with cleaning schedules and pressure-drop monitoring, are less prone to sudden fouling. Combustion and exhaust fans, controlled based on demand, operate near peak efficiency, reducing vibration and heat, thereby extending bearing life. Consequently, unplanned downtime decreases, and maintenance can gradually shift towards a condition-based model, reducing unplanned costs.

Data-driven operation: This represents a systemic shift. Sensors for oxygen, gas, multi-zone temperatures, pressure, flow, and thermal cameras are integrated into a monitoring system, providing real-time KPIs. Setpoints are adjusted based on trends in oxygen, CO, exhaust temperature, pressure differential, and load—replacing guesswork. The system provides early warnings for combustion imbalances, leaks, heat exchanger fouling, shell overheating, and pressure fluctuations. Historical data becomes the equipment's "health record," aiding in operational standardization and faster decision-making during order changes.

Improved operational safety: Benefits are realized in both prevention and response. Safety interlocks for ignition, kiln chamber purging, and hard shutdowns for flame loss or excessive pressure are established and verified. Kiln chamber pressure is stably controlled to prevent sudden cold air ingress and flame roll-out. Gas-tightness of doors, seals, and joints is maintained, reducing the risk of hot gas leakage into work areas. With a controlled temperature field and cooler shell surfaces, the working environment becomes less harsh, lowering risks of thermal burns, heat stress, and fire/explosion incidents.

All these benefits synergize, creating a kiln system that operates stably, efficiently, and safely, ready to meet the plant's long-term output and quality demands.

Economic & financial benefits

From an economic and financial perspective, energy-saving solutions for industrial kiln and furnace system deliver both immediate and long-term value.

Direct energy cost reduction: Through combustion optimization, automatic excess oxygen control, combustion air preheating, improved insulation/gas-tightness, and fan control with Variable Frequency Drives (VFDs), the Specific Energy Consumption (SEC) per unit of product decreases significantly. This benefit is not isolated but cumulative: a comprehensive "foundational" upgrade package often lowers the energy cost per unit product to a competitive level, stabilizing operational costs across shifts and seasons.

Positive cash flow with short payback periods: Many projects have a payback period of 1-3 years based on measurable savings. Specifically, low- or no-investment improvements—such as data-driven O₂ trimming, kiln door sealing, and standardizing programmed heating/cooling procedures—often generate returns immediately, creating internal funds for reinvestment in larger projects.

Lower lifetime costs (Total Cost of Ownership - TCO): Benefits extend beyond the energy bill. Cooler kiln shells and a stable thermal field increase the lifespan of linings and auxiliary equipment. Burners operating optimally, air preheaters on planned cleaning schedules, and fans running at peak efficiency all reduce maintenance costs, minimize unplanned downtime, and mitigate revenue loss from breakdowns. Financially, this is a significant, quantifiable "hidden" value when linked to SCADA/DAS data and maintenance logs.

Improved access to green financing: Energy-saving projects with transparent measurement data (SEC, O₂, exhaust temperature, NO_x), clear economic feasibility, and robust risk/safety management plans align with green credit/ESG criteria. This unlocks access to preferential financing: lower interest rates, longer tenors, or credit guarantees, while also enhancing sustainability ratings for supply chain partners. Investments in heat recovery, digitalization, insulation, and automatic combustion control serve as verifiable "transition assets" for decarbonization roadmaps, demonstrating clear emission impacts.

Enhanced resilience against energy price volatility: Lower energy consumption helps stabilize profit margins even as gas, oil, and electricity prices rise. Heat recovery integration reduces dependency on primary fuel. Digitalization enables strategic load scheduling based on tariff structures and efficient load management. For electric or hybrid kilns, enterprises can shift loads to off-peak hours, integrate on-site renewables, and leverage flexible power purchase agreements to control marginal costs.

These factors collectively “de-risk” the energy profile, improve cash flow predictability, enhance credit ratings, and strengthen confidence in investment decisions.

Therefore, investing in kiln energy efficiency is not merely a cost-saving exercise but a strategic financial tool that enhances competitive advantage and business sustainability.

Table 8. Economic-financial benefit parameters of industrial kiln energy-saving technology groups

Solution group	Investment Level	Operational Cost Impact	Energy Savings vs. Baseline	Typical payback period	Favorable Application Conditions	Key Risks/ Considerations
1. Combustion Optimization & Control (burner upgrade, air	Low–Medium	Slight Reduction (improved	5–15% (plus 1–5% if air distribution/r	0.5–2.5 years	Kilns running multiple shifts; significant O ₂ /CO	Sensor calibration required; safety limits for CO/O ₂ needed; stable kiln

Solution group	Investment Level	Operational Cost Impact	Energy Savings vs. Baseline	Typical payback period	Favorable Application Conditions	Key Risks/ Considerations
distribution, Automatic Excess Oxygen Control, multi-zone control)		control, less downtime)	ecirculation is optimized)		deviation; currently no O ₂ measurement	pressure control required.
2. Waste Heat Recovery (combustion air preheating, recuperators, raw material preheating)	Medium–High (recuperators can be High+)	Reduction (fuel), slight increase in cleaning maintenance	8–25% (air preheaters); 15–35% (recuperators ; can be higher with O ₂ -fuel combustion)	1–3 years (for large loads)	Exhaust gas temperature >350–400°C; long operating hours; sufficient installation space	Fouling/corrosion; increased pressure drop; requires air recirculation, dust pre-filtration, suitable materials.
3. Upgrading Insulation & Refractory Linings (including door sealing)	Medium	Reduction (lower losses, less downtime)	3–10% (higher for batch kilns/short cycles)	1–2 years	Batch/frequently opened kilns; hot kiln shell, high wall heat loss.	Requires thermal-mechanical design; proper kiln drying procedure; burner/circulation adjustment to avoid hot spots.
4. Digitalization & Monitoring (SCADA/DAS, AOOC, additional measurement points; using VFDs for fans)	Low–Medium	Reduction (optimized setpoints; reduced fan power)	3–10%	<1 year for AOOC + VFDs package; 1–2 years for SCADA + analytics	Multi-kiln lines, large production volumes; need for quality traceability.	Noisy/incomplete data → sensor standardization & calibration schedule needed; operator training essential.
5. Heat Integration & Energy Balancing (integrating heat between hot and cold process stages)	Medium	Reduction (fuel & auxiliary electricity)	5–15% of main kiln load; improved overall system efficiency	1–2 years (when leveraging existing infrastructure)	Proximate thermal loads, short piping runs, sufficient temperature differential.	Acid condensation, cross-contamination → material selection, stream segregation, recirculation required.
6. Standardized Operation & Maintenance (preventive maintenance, air preheater cleaning, gas-tightness checks)	Very Low	Reduction	2–6% (little to no investment)	Immediate –<0.5 years	All kilns; especially where procedures are not standardized.	Operational discipline, regular audits; need for a spare parts plan.
7. Fuel Switching (electrification/induction/electric arc; hybrid combustion; biomass/waste-derived fuel co-firing; hydrogen-ready burners)	High–Very High (electrification on highest)	Variable (depends on electricity/fuel prices; requires EMS).	CO ₂ reduction 20–100%; energy savings 0–15% depending on tech/process.	>3 years (typically medium–long term); co-firing can be 1–4 years.	Clean/precise process (electric), or stable biomass/RDF supply; part of decarbonization roadmap.	Electricity/gas infrastructure requirements; NO _x control for H ₂ ; requires TCO analysis, explosion safety assessment, fuel quality control.

Table 9. Estimated Capital Expenditure (CAPEX) Levels

Solution group	Estimated CAPEX (USD)	Scope notes
1. Combustion Optimization & Control (burner upgrade, air distribution, Automatic Excess Oxygen Control, multi-zone control)	20,000 – 250,000	1–4 burners; includes O ₂ /CO sensors, control cabinet/PLC, air duct adjustments; upper range includes low-NO _x /flat-flame burners.
2a. Waste Heat Recovery – Air Preheater (tube bundle/plate/ceramic honeycomb)	80,000 – 1,500,000	Depends on flue gas temperature, material (heat-resistant steel/ceramic/Inconel), flow rate, and installation space.
2b. Waste Heat Recovery – Recuperator (alternating heat charge/discharge)	500,000 – 3,000,000	Requires reversing valves, large ceramic heat exchange mass; economical for continuous high-temperature flue gas operations.
3. Upgrading Insulation & Refractory Linings (including door sealing)	30,000 – 400,000	Depends on lining area, material grade (brick/castable/ceramic fiber/microporous), and extent of mechanical repairs.
4a. Digitalization & Monitoring – Basic Package (AOOC, additional measurement points, VFDs for fans)	15,000 – 120,000	1–2 main fans; O ₂ probes; integration with existing PLC.
4b. Digitalization & Monitoring – SCADA/DAS + Analytics	100,000 – 500,000	Multiple zones/kilns, data servers, analytics/Model Predictive Control (MPC) software (upper range includes MPC).
5. Heat Integration & Energy Balancing	50,000 – 500,000	Gas-gas/gas-liquid heat exchangers, ductwork/piping, recirculation systems, insulation; lower range when leveraging existing infrastructure.
6. Standardized Operation & Maintenance (SOPs, measurement tools, essential spares)	5,000 – 30,000	Training, inspection toolkits, spare gaskets/seals, soot-blowing & safety procedures.
7a. Fuel Switching – Electric (Resistance, Induction, Arc)	500,000 – 5,000,000+	High-power equipment, transformers/rectifiers, cooling systems, electrical upgrades; upper range for large capacity.
7b. Co-firing Biomass/Waste-derived Fuel (burner & feeding system retrofit)	200,000 – 1,500,000	Feeding system, burner/nozzle modifications, dust filter/flue gas system upgrades, storage facility; depends on substitution percentage.
7c. Hydrogen-ready Burners (excluding H ₂ supply/storage system)	50,000 – 300,000	Replacement of burners/valves/controls for H ₂ compatibility; H ₂ production/storage infrastructure is separate.

Environmental - social benefits and compliance

Energy-saving projects for industrial kiln and furnace system deliver significant environmental and social value while strengthening a company's compliance and ESG (Environmental, Social, and Governance) management capabilities.

Reduced greenhouse gas (GHG) emissions is a direct result of lowering fuel consumption. By optimizing combustion, trimming oxygen levels (Automatic

Excess Oxygen Control), recovering waste heat, and improving insulation and gas-tightness, Scope 1 CO₂ emissions are reduced proportionally to the fuel saved. Furthermore, a fuel-switching roadmap—electrification, co-firing biomass/waste-derived fuels, or preparing for hydrogen—creates pathways for deep emissions reductions at the plant level, helping businesses move closer to carbon neutrality goals. Digital measurement and standardized energy/emission reporting also establish a transparent and consistent foundation for tracking annual emission reduction progress.

Local pollution mitigation benefits run parallel to energy efficiency. Upgrading to low-NOx burners, optimizing air distribution, applying staged combustion and/or flue gas recirculation, combined with oxygen level control, directly reduces NOx and CO emissions from the combustion chamber. This also curtails odors, black smoke, and the risk of incomplete combustion. Improved linings, insulation, and standardized gas-tightness reduce hot gas leakage into workspaces, thereby improving the in-plant microclimate. When necessary, this can be combined with suitable particulate and gas treatment solutions (e.g., bag filters, wet/dry scrubbers, Selective Catalytic/Non-Catalytic Reduction for NOx) to ensure emissions consistently meet legal limits, remain stable over time, and do not depend on operational "workarounds."

Legal compliance and certification readiness is enhanced. Lowering specific energy consumption and controlling emissions makes it easier for businesses to meet national and regional energy and environmental standards, from energy audits and performance labeling to emissions management schemes (such as carbon pricing or emission caps). A digital infrastructure (data monitoring/acquisition systems, performance dashboards) alongside standardized measurement records enables rapid data verification during inspections, reducing preparation time and procedural violation risks. In global supply chains, companies with transparent energy and emissions management systems often achieve higher sustainability scores, facilitating long-term contracts and participation in green procurement programs.

Social benefits and occupational safety are substantial. With better-controlled thermal fields and cooler kiln shell temperatures, radiant heat in work areas is reduced. Coupled with improved gas-tightness and optimized fan/pressure systems, the work environment becomes cooler, with less dust and toxic gas, lowering risks of thermal burns and incidents. Safety interlocks (for purging, flame failure, over/under-pressure), standardized operating procedures, and regular training strengthen safety culture, reduce incident frequency, and cut lost workdays from accidents. For the surrounding community, reductions in NOx/CO/dust and

controlled noise from fans and ducts lessen environmental impact, minimizing complaints and legal risks.

Corporate image and ESG value, though intangible, are sustainably strengthened. Transparently publishing energy and emissions data, outlining a viable decarbonization roadmap, and demonstrating improvements in occupational health and safety enhance a company's reputation with customers, investors, and regulators. This builds brand value, supports access to green financing, and opens opportunities to join industry emission-reduction alliances.

In summary, each saved kWh or Nm³ of fuel not only cuts costs but also translates into tangible ESG points, reinforcing a company's compliance capacity and long-term competitiveness.

Table 10. Summary of environmental–social and compliance benefits

Solution group	Direct CO ₂ Reduction (%)	NO _x /CO/ Particu-late Reduction	Work Environment Improvement (Heat, Gas, Noise)	HSE (Health, Safety, Environment) Impact	Compliance Readiness	Data Verifiability (for Sustainability Reports/Indicators)	Notes
1. Combustion Optimization & Control (burner, air distribution, oxygen trimming, multi-zone control)	5–15	NO _x : 20–50% reduction with low-NO _x burners; significant CO reduction.	More uniform thermal field; reduced hot gas leakage; lower fan noise with VFDs.	High (interlocks, purge sequences, pressure control).	High – facilitates standards compliance, eases audits.	High – O ₂ /CO, temperature, pressure data logged in monitoring system.	Foundation for all emission reduction programs.
2. Waste Heat Recovery (air preheaters, recuperators; raw material preheating)	8–35	Indirect NO _x /CO reduction through stable operation.	Less waste heat released; cooler workshop environment.	Medium (requires managing pressure drop, fouling).	Medium–High – reduces overall plant emissions.	Medium–High – monitored via temperature/pressure differentials, flow rates, SEC.	Requires control of fouling, corrosion, acid condensation.
3. Upgrading Insulation & Refractory Linings (incl. door sealing)	3–10	Indirect reduction due to more stable combustion.	Reduced radiant heat; kiln shell temperature lowered by ~10–30°C.	Medium.	Medium – supports safety and environmental conditions.	Medium – tracked via shell temperature, gas leakage, SEC.	Requires proper thermal-mechanical design and kiln drying procedure.
4. Digitalization & Monitoring (data monitoring, O ₂ trimming, VFDs, thermal imaging)	3–10	CO/NO _x reduction by maintaining target O ₂ ; detects incomplete combustion.	Stable pressure and flow; reduced fan noise.	High – early warnings, fewer incidents.	Very High – data readily available for inspections and reporting.	Very High – real-time KPIs (SEC, O ₂ , NO _x , pressure diff...).	Enabler for advanced control; provides complete digital records.
5. Heat Integration & Energy Balancing	5–15	Not direct; reduces overall	Reduced local hot spots; less waste	Medium.	Medium – easier to justify at plant level.	Medium – measures heat exchange,	Requires stream segregation,

Solution group	Direct CO ₂ Reduction (%)	NO _x /CO/ Particulate Reduction	Work Environment Improvement (Heat, Gas, Noise)	HSE (Health, Safety, Environment) Impact	Compliance Readiness	Data Verifiability (for Sustainability Reports/Indicators)	Notes
		workshop emissions.	heat released into workshop.			temperatures, flow rates.	bypasses, suitable materials.
6. Standardized Operation & Maintenance (SOPs, preventive maintenance, heat exchanger cleaning, gas-tightness checks)	2–6	CO reduction via standardized ignition/purge; stable dust/noise levels.	Safer working conditions; gas leakage nearly eliminated.	High.	High – meets safe operating requirements.	High – logs, checklists, on-site evidence.	Low-cost, immediate effectiveness.
7. Fuel Switching (electrification/hybrid; biomass/RDF co-firing; hydrogen-ready)	20 – 100	Electrification: near-zero NO _x ; hydrogen requires NO _x control; co-firing may increase particulates without treatment.	Reduces hot gases and soot; noise varies by technology.	Medium–High (requires electrical/hydrogen safety assessment).	High for emission reduction strategy; depends on local regulations.	Medium–High – requires emission monitoring and fuel traceability systems.	Long-term solution; requires TCO analysis and energy infrastructure.

2.4 Assessing the feasibility of applying energy-efficient industrial kiln technology

Below is a detailed guide for assessing the technical feasibility of applying EE technologies/solutions to industrial kiln and furnace system (excluding boilers, thermal oil heaters, and drying ovens). The content follows the precise sequence of "prerequisite conditions → measurement methods → reference thresholds → risks and mitigation measures," aiding in rapid decision-making during the pre-feasibility stage and providing the basis for detailed surveys.

Site – existing technology

First, review spatial and structural constraints:

- » **Installation space:** Is there sufficient space for installing the combustion air preheater/recuperator, bypass ducting, new chimney, supports, and maintenance platforms? Minimum working clearance around hot equipment must be ≥ 800 mm; floor load capacity must be $\geq 5\text{--}8$ kN/m² for metallic heat exchanger units; check floor deflection when placing ceramic honeycomb units.
- » **Existing air/flue gas ducting:** Review the layout and dimensions; check for existing tee/branch connection points; verify the presence of isolation valves for testing individual branches. Determine the existing pressure drop (Pa) to facilitate fan recalculation.
- » **Kiln structure:** Assess the shell, insulation layer, flanges, inspection ports, and measurement points. Evaluate the feasibility of a planned shutdown (e.g., 48–72 hours) for executing hot work installation items.
- » **Auxiliary infrastructure:** Verify the availability and capacity of power supply, compressed air, cooling water, and lifting/hoisting systems (cranes, hoists) for installation support.

If the preceding items (related to heat recovery projects) are severely deficient (e.g., no feasible ductwork/installation space available, inability to schedule necessary downtime due to continuous production cycles), these factors effectively act as blocking points for implementing waste heat recovery solutions. In such cases, the focus must shift toward alternative measures that require zero or minimal capital investment, such as combustion optimization & control initiatives.

Fuel – air supply system

The objective is to assess the "controllability" of the combustion process. This evaluation focuses primarily on three key factor groups:

Fuel: Assessing the variability range of fuel quality (particle size, moisture content, ash, and calorific value) and its

- » cleanliness/consistency. This is particularly critical when implementing high-efficiency combustion solutions such as low-NO_x burners, flat-flame burners, or oxy-fuel technology. Concurrently, the feasibility of achieving standardized, continuous fuel feeding must be evaluated, especially for fluidized bed and grate-fired kilns.
- » **Combustion air:** Evaluate the forced-draft fan, its pressure–flow characteristics, and the available static pressure headroom ($\geq 10\text{--}20\%$) to compensate for pressure losses that arise when integrating a heat exchanger. Assess the capability for zone-based air distribution (zone control), the quality of damper control, and the integrity of gasket seals.
- » **On-site measurement:** Assess the installation of high-temperature O₂/CO probes, temperature and pressure measurement points within the kiln chamber, and the feasibility of adding access ports for infrared sensors. If not yet available, this is a mandatory investment item for any combustion optimization and automation plan.

Reference thresholds for best practices include: dry excess O₂ after the combustion chamber at 2–4% (for gas firing) or 3–5% (for oil firing); intra-zone temperature fluctuation within $\pm 5\text{--}10$ °C; and a CO concentration < 200 ppm during stable operation. Significant deviations from these values typically indicate a bottleneck in the control system or in the air-fuel mixing process.

Exhaust gas – environmental treatment

Upgrade solutions such as improving combustion efficiency, implementing heat recovery, or increasing combustion air flow will alter the characteristics of the flue gas. Consequently, the following issues must be considered:

- » **Post-retrofit flue gas temperature and flow rate:** Is there a risk of falling below the acid dew point (SO₃/H₂SO₄), causing chimney/fan corrosion? Select appropriate materials/lining or maintain a minimum exhaust temperature setpoint.
- » **Dedusting/abatement equipment (cyclone, bag filter, ESP, De-SO_x/De-NO_x):** Check capacity for handling potential increases in dust/gas load. Ensure compliance with current emission standards will not be compromised.
- » **CEMS or monitoring plan:** Early identification of sampling point location, heated sample line, analyzer cabinet for any new O₂/CO/NO_x probes.

If existing treatment units are already operating at their limit or materials cannot withstand the new operating regime, the associated environmental upgrade costs must be added to the CAPEX analysis.

Process line integration – technological impacts

Evaluate cross-impacts between the kiln and upstream/downstream process stages:

- » Inter-stage thermal balance: Could a shortened heat-up time/cycle cause overheating in subsequent stages? Risk of localized hot spots leading to product cracking/warping (ceramics, glass, non-ferrous metallurgy)?
- » Drives & mechanisms: Could variations in forced/induced draft air flow cause vibration, exceed kiln chamber pressure limits (positive/negative), or lead to smoke accumulation?
- » Inter-process heat recovery: When implementing heat integration (e.g., using waste gas to dry molds/pipes), ensure coordinated control of bypass and safety valves to prevent kiln load hangs.
- » MOC/Change control procedure recommended: Document the change, perform risk assessment, define low-load testing protocol, implement staged ramp-up, and establish step-by-step "go/no-go" criteria.

Process line integration – technological impacts

This is the prerequisite for translating theoretical benefits into real savings:

- » IO & Algorithms: Sufficient AI/DI/DO channels for adding sensors and valves; built-in function blocks for ramp-soak, cross-limit, and interlocked safety purge cycles; data logging at 1–5 s/point for KPI analysis (SEC, NO_x, temperature deviation).
- » VFD/Pressure Control Valves: For forced draft/induced draft fans and circulation pumps (if any) to enable linear load-following and reduce overcontrol.
- » Alarms – Safety Interlocks: High CO, low/excess O₂; pressure/temperature exceeding setpoints; verified trip logic; periodic SIL/Proof Test procedures. Without the appropriate control layer, the benefits from high-efficiency burners/heat recovery are often significantly diminished or unstable.

Refractory – insulation lining material compatibility

Increased surface temperatures or changed thermal/moisture profiles will directly impact lining lifespan:

- » Hot face material selection: High emissivity refractory bricks/castables; microporous/ceramic fiber insulation for high heat loss areas; design for expansion joints, anchors, thermal bridging; door sealing.
- » Cycling – thermal shock: Analyze heating/cooling curves to determine material shrinkage; upgrade materials at "hot spots" (doors, corners, joints) to prevent cracking/spalling.

- » High radiation: Consider high-emissivity surface coatings/paints and control hot spots via burner adjustment/hot air circulation.
- » Good operational targets: Reduce kiln shell temperature by 10–30 °C; reduce wall heat losses by 15–40%; reduce heat-up time while staying within the refractory lining's thermal stress limits.

Technical "Go/No-Go" criteria and testing

Before finalizing investment, define minimum criteria and load testing protocols:

- » Acceptance criteria: Stable dry O₂/CO across the product range; NO_x/PM within standards; zone temperature deviation ≤ ±5–10 °C; fan vibration/noise within limits; no acid dew point in the stack.
- » Testing protocol: Off-line algorithm simulation; FAT/SAT for PLC; staged hot commissioning (40–60–80–100% load), with 24–72 hours of data logging; acceptance based on energy KPIs (SEC), product quality, and safety performance.
- » Standardized operation & maintenance: Issue SOPs for charging/discharging, door operation, purging, and product changeovers; establish a preventive maintenance plan for burners, nozzles, pumps/fans; provide training on operation and fire/explosion safety.

Typical risks & control measures

- Flame instability due to low O₂ concentration or poor air distribution: requires implementing O₂-trim control, rebalancing the air system, and establishing CO thresholds/safety limits for operational control.
- Corrosion from the acid dew point due to a deep reduction in flue gas temperature: necessitates selecting Inconel or ceramic materials, combined with a hot gas bypass or maintaining a minimum exhaust temperature setpoint.
- Hot spots and refractory lining cracks from increased radiant flux after retrofitting: requires using thermal shock-resistant materials, adding anchors, and adjusting the burner flame pattern.
- Fan and stack overload from increased pressure drop: requires recalculating the operating point, replacing impellers/fans or using VFD control, and considering the installation of a bypass line.

Table 11. Summary of technical feasibility assessment criteria

Assessment Category	Key Indicator/Measure	Suggested Threshold for "Go"	Evidence/Documentation Required	Risk if Not Met
Site & Structure	Installation space; floor loading; shutdown duration	Feasible layout exists; floor load $\geq 5-8$ kN/m ² ; planned shutdown ≥ 48 hours	2D/3D layout drawings, site survey report, approved shutdown schedule	Inability to install/constr uct safely
Ducting & Fans	Static pressure reserve; added pressure loss	Pressure reserve $\geq 10-20\%$; new fan operating point within efficiency curve	Fan performance curve, measured pressure drop (ΔP), updated network calculation	Fan overload, vibration, noise; insufficient air/gas flow
Fuel & Feeding	Moisture/size variation; feed stability	Variation range falls within burner design specifications	Fuel analysis reports; existing/reviewed SOP for feeding	Incomplete combustion, high CO emissions
Combustion Air & Instrumentation	O ₂ /CO online; zone temperature/pressure sensors; VFDs	Presence of O ₂ /CO probes; zone sensors; VFDs on main fans	IO list, P&ID, instrument calibration records	Poor load-following control, suboptimal combustion
Control & SCADA	Cross-limit, ramp-soak, safety interlocks	Algorithm blocks available; data resolution ≤ 5 seconds	URS/FDS documents, FAT/SAT reports, sample trend data	Unstable energy benefits; safety risks
Environment & Gas Treatment	Dust/gas load capacity; acid dew point	Emission control equipment has spare capacity; materials suitable for new temperature regime	Stack test reports, dew point calculation, material specifications	Failure to meet emission standards; corrosion
Lining & Insulation	Thermal load, shock resistance; joint/anchor design	Lining withstands new thermal profile; heat loss reduction target of 15–40%	Material data sheets, thermal calculations, IR scan reports	Cracking, spalling, hot gas leaks
Quality & Productivity	Zone temperature deviation; heat-up time	Zone $\Delta T \leq \pm 5-10$ °C; heat-up time to setpoint is reduced	Trial run data logs, product quality reports	Product quality deviations, increased scrap rate

Assessment Category	Key Indicator/Measure	Suggested Threshold for "Go"	Evidence/Documentation Required	Risk if Not Met
Safety & Compliance	CO/O ₂ interlocks; operational SOPs; fire safety	SOPs/LOTO procedures exist; interlocks are tested and functional	Training records, interlock testing checklists	Fire/explosion incidents, unplanned emergency shutdowns

2.5 Classification of enterprises suitable for technology application

To select the "right remedy – right dose," enterprises can be classified based on certain operational characteristics and resource constraints. Each group is paired with a prioritized solution package, helping to maximize investment efficiency and reduce implementation risks.

Based on scale and investment capacity

Large enterprises, characterized by multi-shift operation and stable production output, should prioritize medium-to-high CAPEX solution packages that deliver sustainable efficiency. Recommended measures include: waste heat recovery (e.g., air preheaters, recuperators, regenerators), digitalization at SCADA/DAS (Data Acquisition System) levels coupled with data analytics, multi-zone combustion optimization, pressure control using VFDs (Variable Frequency Drives) for fans, and upgrades to refractory linings and insulation. Additionally, consideration should be given to heat integration across different process stages and formulating a roadmap for fuel transition (hybridization, electrification, or H₂-ready systems).

Small and medium-sized enterprises (SMEs), often constrained by limited budgets, are advised to begin with "no-/low-cost" measures. These include: sealing kiln doors, fine-tuning oxygen (O₂) levels based on operational data, installing VFDs for fans, establishing SOPs (Standard Operating Procedures) for operation and maintenance, performing local insulation upgrades, and adding critical monitoring points (e.g., O₂/CO, temperature, and differential pressure). Once sufficient data is gathered and energy savings generate a positive cash flow, expansion into compact heat recovery (e.g., shell-and-tube or plate heat exchangers) and basic automation systems can be pursued.

Based on kiln system status

For old, low-efficiency, and high-emission kiln systems, a comprehensive "foundational upgrade" package must be implemented. This includes safety and gas-tightness inspections, replacement with high-efficiency or

low-NOx burners, addition of safety instrumentation and interlocks, refurbishment of refractory and insulation systems, and installation of an appropriately sized waste heat recovery system (with priority given to metallic or ceramic recuperators). Achieving consistent product quality and operational stability is the primary objective, with consideration for increased production capacity only after these are secured.

For new or partially modernized kiln systems, the focus shifts to data-driven optimization. This involves implementing O₂-trim control, multi-zone control, and Model Predictive Control (MPC) or AI algorithms at key sensitive points. The scope should also be expanded to include heat integration, internal logistics optimization such as preheating materials or drying molds/piping, and standardizing a KPI dashboard to support energy audits, ESG management, and continuous improvement programs.

Based on process operation mode

For continuous kilns with long operating cycles: Significant efficiency improvements are achieved by implementing waste heat recovery systems (recuperators or regenerators), controlling kiln chamber pressure, optimizing air distribution, and deploying continuous 24/7 digital monitoring systems. Furthermore, implementing heat integration between kilns or process stages can create a synergistic effect for both energy savings and operational stability.

For batch/cyclic kilns with high door-opening frequency: The focus of upgrades should include enhancing insulation and refractory lining with lightweight, high-emissivity materials; improving door sealing; optimizing ramp-soak algorithms; and utilizing hot gas recirculation to shorten heating time, reduce thermal mass, and consequently lower specific energy consumption.

Based on product quality requirements

Temperature/atmosphere-sensitive processes (e.g., ceramics, glass, precision heat treatment): Focus on achieving uniform temperature fields, precise O₂/CO control, flat-flame/low-NOx burners, multi-point thermal imaging/sensors, and Model Predictive Control (MPC) to minimize hot spots and preserve surface integrity.

Less sensitive processes (e.g., billet/heating for forging/rolling, drying/calcining of basic refractories): More aggressive cost-saving measures are viable, such as O₂-trim control, deep waste heat recovery, and heat integration for auxiliary loads.

Based on legal & environmental constraints

Entities under emission compliance/carbon pricing pressure: Priority should be on low-NO_x burners, staged/FGR (Flue Gas Recirculation) control, O₂-trim, and appropriate dust/NO_x abatement systems. Standardize monitoring and data systems to demonstrate compliance. Consider roadmaps for biomass/RDF co-firing or partial electrification to reduce Scope 1 CO₂ emissions.

Based on fuel availability & energy infrastructure

The optimal strategy is to implement co-firing and progressively increase the fuel substitution rate; retrofit burners and fuel feeding systems to accommodate the specific fuel characteristics; implement corrosion and fouling control; and apply waste heat recovery and digitalization solutions to lower the baseline energy consumption.

When the power grid is robust and the carbon emission reduction targets are ambitious:

Consider electrifying heating processes (using resistance, induction, or electric arc technologies) or configuring a hybrid electric–combustion system. If the strategic direction includes hydrogen usage, prepare by installing compatible or H₂-ready burners to reduce future conversion costs.

Based on organizational & human resource readiness

In cases where the operations and maintenance team possesses strong capabilities and a data-driven culture is already established: Enterprises can accelerate the adoption of advanced control technologies such as Model Predictive Control (MPC) or AI, implement data-driven optimization, and integrate cross-shift data systems to support analytics and continuous improvement.

In cases where operational resources are limited and procedural discipline is inconsistent: The focus should be on a "standardize first" roadmap. This includes finalizing Standard Operating Procedures (SOPs), conducting training, implementing safety checklists, and deploying basic-level digitalization (e.g., O₂/CO and temperature measurement) before investing in advanced control solutions.

Table 12. Priority order for implementing energy-saving technology solutions

Enterprise group	Implementation priority (in order)	Implementation notes
Large, 24/7 operation, under ESG pressure	1) Combustion optimization & O ₂ -trim; 2) Deep waste heat recovery; 3) SCADA digitalization + analytics; 4) Heat integration; 5) Fuel transition roadmap (hybridization/electrification/H ₂ -ready)	Organize the project modularly, validate with SEC–emission KPIs; standardize data for auditing.

Enterprise group	Implementation priority (in order)	Implementation notes
Small & Medium, limited budget	<ol style="list-style-type: none"> 1) SOP – Sealing – Local insulation improvement; 2) O₂-trim + VFDs; 3) Compact recuperator; 4) Simple KPI dashboard 	Use "no/low-cost" savings as revolving capital for larger items.
Old, low-efficiency kiln systems	<ol style="list-style-type: none"> 1) Safety – Gas tightness – Refractory lining; 2) Replacement/upgrade to low-NOx burners; 3) O₂/CO measurement & pressure control; 4) Recuperator; 5) SCADA 	Prioritize stabilizing product quality before increasing load.
Continuous kilns	<ol style="list-style-type: none"> 1) Recuperator/regenerator; 2) O₂-trim & combustion air distribution; 3) Pressure control + VFDs; 4) Heat integration 	Ensure fans/flue systems can handle increased ΔP after heat recovery installation.
Batch/short-cycle kilns	<ol style="list-style-type: none"> 1) Lightweight, high-emissivity insulation – lining; 2) Door sealing; 3) Hot gas recirculation; 4) Ramp–soak profile optimization; 5) O₂-trim 	Focus on reducing heat-up time and thermal mass.
Quality-sensitive processes	<ol style="list-style-type: none"> 1) Flat-flame/low-NOx burners; 2) Multi-point sensors + thermal camera; 3) Model Predictive Control (MPC); 4) Dew-point controlled heat recovery 	Establish CO/O ₂ "guardrails" and quality control charts.
Under legal/carbon pricing pressure	<ol style="list-style-type: none"> 1) Low-NOx burners + O₂-trim; 2) Filtration/abatement solutions; 3) Biomass/RDF co-firing or partial electrification; 4) Standardized monitoring 	Align investment roadmap with annual emission targets and carbon cost.

2.6 Barriers and supporting solutions

Implementing energy-saving technologies for industrial kiln and furnace system often encounters a complex set of "technical – financial – organizational – market" barriers. To ensure project feasibility and sustainability, it is essential to identify barriers within the specific context of the enterprise and then apply the correct supporting tools. Below is a summary of the main barrier groups and recommended solution packages.

Technical barriers

Many facilities operate outdated kilns with inconsistent designs, have limited space for installing air preheaters/regenerators, operate air/flue gas ductwork at near capacity with insufficient fan static pressure margin, suffer from degraded refractory lining causing significant air/gas leaks, and lack comprehensive instrumentation and control (e.g., missing O₂/CO probes, insufficient temperature/pressure measurement points). Highly variable fuel quality (moisture, impurities, calorific value) leads to unstable combustion. Furthermore, existing flue gas treatment systems (dust filters/NO_x reduction) often have little spare capacity to accommodate new operating conditions. This combination of factors makes it difficult to quantify project benefits and increases safety and operational risks.

Supporting solution:

- » Conduct standardized pre-feasibility studies; test fans and stacks and recalculate operating points.
- » Implement a minimum instrumentation layer (O₂/CO, temperature, pressure differential).
- » Standardize SOPs and conduct trial runs at different load levels.
- » Perform heat and mass balance simulations, calculate acid dew points, and model heat distribution.
- » Select heat exchanger configurations suitable for the materials, design bypass systems, and implement safety interlocks.

Investment cost barriers

CAPEX for heat recovery, low-NO_x burners, digitalization/SCADA systems, or refractory retrofits can be high relative to available cash flow. Additionally, increased OPEX for cleaning and calibration makes companies cautious.

Supporting solutions:

- » Mobilize green/ESG credit, co-financing mechanisms, or credit guarantees.

- » Apply ESCO (Energy Service Company) models with guaranteed performance contracts.
- » Use financial leasing for measurement and control equipment.
- » Implement accelerated depreciation schedules and tax incentives for energy efficiency investments. Include performance-based clauses in contractor agreements to share risk

Information & measurement barriers

There is often a lack of baseline data (SEC, O₂, CO, flue gas temperature, pressure drops) and industry benchmarks, as well as no standardized Measurement and Verification (M&V) methodology, making it difficult to gain internal and financial approval.

Supporting solutions:

- » Develop standardized RFQ/URS templates; provide M&V guidelines and KPI dashboard frameworks.
- » Conduct rapid 2–4 week measurement campaigns to establish baselines.
- » Build a library of case studies and standard industry indices.
- » Require contractors to deliver pre- and post-retrofit data in a unified format.

Technical personnel and change management barriers

There is often a lack of baseline data (SEC, O₂, CO, flue gas temperature, pressure drops) and industry benchmarks, as well as no standardized Measurement and Verification (M&V) methodology, making it difficult to gain internal and financial approval.

Supporting solutions:

- » Develop standardized RFQ/URS templates; provide M&V guidelines and KPI dashboard frameworks.
- » Conduct rapid 2–4 week measurement campaigns to establish baselines.
- » Build a library of case studies and standard industry indices.
- » Require contractors to deliver pre- and post-retrofit data in a unified format.

Downtime & product quality risk barriers

Tight production schedules, concerns that thermal profile changes will affect product quality, and difficulty in accepting prolonged downtime for installation and kiln drying.

Supporting solutions:

- » Modularize project scope and schedule installations during shift gaps ("piggybacking").

- » Implement a phased ramp-up by load step; secure quality performance warranties.
- » Use pre-fabricated materials and modular installation to shorten kiln drying time.
- » Conduct A/B testing comparing the upgraded kiln with a control kiln.
- » Develop contingency plans with bypass systems to avoid complete production line shutdowns.

Market & supply chain barriers

Unstable supply of biomass/RDF; long lead times for imported burner/spare parts and probes; fragmented after-sales service networks.

Supporting solutions:

- » Establish procurement framework agreements with multiple suppliers.
- » Implement fuel quality control based on standards.
- » Maintain strategic spare parts inventory.
- » Develop localized service capabilities or authorized dealerships.

Policy & institutional barriers

Many companies lack clear economic incentives due to the absence of widespread carbon pricing or mandatory standards; there is a lack of programs supporting data-driven operations.

Supporting solutions:

- » Recommend implementing Minimum Energy Performance Standards (MEPS).
- » Develop sector-specific emission reduction programs.
- » Apply Time-Of-Use (TOU) electricity tariffs and load-shifting mechanisms.
- » Establish funds to support energy audits and digital metering initiatives.
- » Develop technical guidebooks and industry-scale demonstration programs.

Table 13. Summary of barriers and support needs

Group of barriers	Typical description	Impact on project	Recommended mitigation / support solution	Responsible entity	Monitoring indicator / KPI
Technical – Infrastructure	Lack of space/ducting; fans/stack at capacity limit; gas leaks; lack of instrumentation	Unstable benefits, safety risks	Detailed survey; addition of O ₂ /CO, temperature, ΔP sensors; fan re-selection/calculation; installation of bypass; dew point	Enterprise + Contractor	Completion of survey report; sufficient I/O channels available; fan ΔP/performance meeting

Group of barriers	Typical description	Impact on project	Recommended mitigation / support solution	Responsible entity	Monitoring indicator / KPI
			simulation; safety SOPs.		target; stable O ₂ /CO trends.
Investment Cost	High CAPEX; concerns about OPEX for cleaning/calibration	Decision delays, scope reduction	Green/ESG credit lines, ESCO models, equipment leasing; tax incentives/accelerated depreciation; performance-based contracts.	Bank/ESCO + Enterprise	Payback period/NPV meeting threshold; proportion of preferential capital in total CAPEX.
Information – M&V	Lack of baseline SEC, O ₂ , CO, flue gas temp; no standardized M&V protocol	Difficulty in approval and commissioning	2–4 week measurement package; KPI dashboard; RFQ/URS templates; unified M&V procedure.	Enterprise + Consultant	Baseline data approved; post-retrofit M&V report completed.
Personnel – Change Management	Limited operational/calibration skills; resistance to change	Product quality deviations, "fade" of achieved benefits	Role-based training; detailed SOPs; on-site coaching; KPI-linked reward/penalty system.	Enterprise	Percentage of staff certified; SOP compliance rate; number of operational incidents/month ↓.
Production Shutdown Time	Tight order schedule; fear of quality risks	Project delays, scope cuts	Modular design/phased installation; staged ramp-up commissioning; quality performance warranty; prefabrication of components; use of bypass systems.	Enterprise + Contractor	Milestone completion on schedule; zero quality defect rate during acceptance.
Supply Chain	Unstable biomass/RDF fuel supply; long equipment lead times	Fluctuating performance; project commissioning delays	Framework procurement agreements; fuel quality standards; strategic inventory of key parts; authorized service agency partnerships.	Enterprise + Association + Supplier	On-time delivery rate; fuel quality meeting standard specifications.

Group of barriers	Typical description	Impact on project	Recommended mitigation / support solution	Responsible entity	Monitoring indicator / KPI
Policy – Institutional	Lack of economic incentives; few digitalization support programs	Low investment priority	Minimum Energy Performance Standards (MEPS); funding for measurement/audit programs; Time-Of-Use / Demand Response schemes; technology demonstration programs.	Regulatory Body + Donor/Sponsor	Number of participating enterprises; amount of verified energy savings.

CHAPTER 3. PRACTICAL APPLICATIONS AND CASE STUDIES

3.1 Practical applications in Vietnam

Application of waste heat recovery power generation technology in the cement industry

Tan Thang Cement Factory (Tan Thang Commune, Quynh Luu District, Nghe An Province) operates a clinker production line with a capacity of 5,000 tons per day. Since 2025, the company has invested in a Waste Heat Recovery (WHR) power generation system for this line. The system has a design capacity of 9,000 kW, a gross power output of 8,650 kW, and a net output of 8,035 kW.

The system was invested in by Tan Thang Cement Joint Stock Company, with Shanghai Conch Kawasaki Engineering Co., Ltd. serving as the Engineering, Procurement, and Construction (EPC) contractor responsible for design, equipment supply, and installation. The WHR system recovers residual heat from exhaust gases at temperatures ranging from approximately 250–400°C, captured at the preheater cyclone tower and the clinker cooler (grate cooler). The hot gases are channeled through heat exchangers and high-pressure boilers, and subsequently passed through a steam turbine to generate electricity. All the electricity produced is integrated into the plant's internal power grid



Figure 1. Waste heat recovery system from the emission process at Tan Thang cement factory

Regarding energy and environmental efficiency, the WHR system utilizes nearly 100% of the waste gas stream's heat for electricity generation, meeting approximately one-third of the entire plant's power demand. This is equivalent to saving 25–30% of the electricity that would otherwise need to be purchased from EVN. According to the company's assessment, this self-generated electricity saves the plant approximately VND 78–80 billion in electricity costs annually, while simultaneously reducing the load on the national transmission grid during peak demand periods.

Alongside economic benefits, the system also contributes to an annual reduction of approximately 40,000 tons of CO₂ emissions. The dust concentration in the treated exhaust gas has decreased from about 30 mg/Nm³ to around 10 mg/Nm³, meeting stringent environmental standards comparable to those of the EU and G7.

In terms of investment efficiency, the project is evaluated as having strong financial viability, with a payback period of approximately 6 years, attributed to the significant annual electricity cost savings mentioned above.

Given the electricity savings rate of 25–30% and the scale of CO₂ emission reductions, this case can be considered a model for waste heat recovery power generation solutions in the cement industry – a major energy consumer and emitter. The project simultaneously contributes to "green cement" goals, the implementation of the National Green Growth Strategy, and the commitment to achieve Net Zero emissions by 2050. It serves as a crucial basis for considering the replication of WHR technology for other clinker kiln lines across the country.

Table 14. Summary of information on the waste heat recovery power generation project at Tan Thang Cement Joint Stock Company

Category	Information
Enterprise name	Tan Thang Cement Joint Stock Company
Location	Tan Thang Cement Factory, Bac Thang Hamlet, Quynh Thang Commune, Nghe An Province
Sector	Clinker and cement production
Type of EE solution	Waste Heat Recovery Power Generation (WHR)
Investment objective	To utilize waste heat from exhaust gases in the clinker production process to generate electricity, reducing purchased electricity costs and lowering environmental emissions.
Related production line/industrial kiln	5,000 tons/day clinker production line
WHR system design capacity	9,000 kW (design capacity)
Power generation capacity	8,650 kW (gross), 8,035 kW (net)

Category	Information
Heat recovery source	Waste heat from the clinker cooler grate and preheater cyclone tower, at temperatures approximately 250–400°C.
Key Principle/Configuration	Hot exhaust gases pass through heat exchangers – high-pressure boilers – steam turbine – generator. The generated electricity is fed into the plant's internal power grid.
Commercial operation date	April 30, 2025 (commercial operation), system inaugurated and handed over in 2025.
Contractor/Technology provider	Shanghai Conch Kawasaki Engineering Co., Ltd (design, equipment supply, and installation)
Percentage of factory's electricity demand met	The WHR system meets approximately one-third of the plant's total electricity demand; equivalent to saving 25–30% of electricity that would be purchased from EVN.
Estimated annual electricity cost savings	Approximately VND 78–80 billion/year in electricity costs (estimated based on self-generated electricity output).
Environmental benefits	Reduces emissions by approximately 40,000 tCO ₂ /year; post-treatment dust concentration reduced from ~30 mg/Nm ³ to ~10 mg/Nm ³ , meeting EU/G7 environmental standards.
Preliminary payback period	Approximately 6 years, based on the value of annual electricity cost savings.
Construction duration	Actually shortened from an original ~15 months (per contract schedule) to 9.5 months.
Notes	The project is evaluated as a model solution for waste heat recovery power generation in the cement industry, contributing to "green cement" goals and Vietnam's Net Zero roadmap.

Investment in a mobile tunnel kiln at Tien Hung Tunnel Brick Company Ltd. (Bac Giang)

Tien Hung Tunnel Brick Company Limited (Luc Nam District, Bac Giang Province) is an enterprise specializing in manufacturing construction bricks from fired clay. Previously, the company used traditional Hoffmann kiln technology, which was characterized by high energy consumption, significant dust and exhaust emissions, unstable brick quality, and high labor intensity during the brick loading and unloading stages.

To improve energy efficiency and enhance competitiveness, the Company decided to invest over 80 billion VND in a modern, closed-loop brick production line using a mobile tunnel kiln (also known as a humpback kiln), with a capacity of approximately 30 million bricks per year. This modern tunnel kiln features a fixed firing chamber. Carts carrying green (unfired) bricks move through a temperature-controlled "tunnel," passing through automated zones for drying, preheating, firing, and cooling.

The new kiln system is highly automated. Operational controls, temperature adjustments, and cart speeds are managed from a central control room. The company also invested in two brick-handling robots for setting green bricks and unloading finished bricks from the kiln. This automation allows the plant to operate with a small team of technicians, replacing approximately 40 manual laborers previously required. The kiln's steel shell is lined with high-efficiency insulation, minimizing heat loss through the walls. Furthermore, instead of using field clay, the company shifted to using hill soil, mine overburden, coal slurry, kiln slag, and waste bricks/tiles. This change contributes to utilizing secondary resources and reduces pressure on agricultural land.

The transition from the Hoffmann kiln to the mobile tunnel kiln increased production by approximately 30% compared to the old system, while significantly reducing fuel consumption per brick. This is due to better heat recovery and reduced heat loss through the kiln shell. The new kiln is "energy-saving and significantly reduces emissions" compared to the old technology – crucial metrics for building materials companies in the face of rising energy costs and increasingly stringent environmental regulations.

Environmentally, the sealed structure and improved combustion control of the mobile tunnel kiln have drastically reduced dust and gas emissions compared to the open Hoffmann kiln. Combined with the use of alternative raw materials like hill soil, overburden, slag, and broken bricks, the project helps reduce agricultural land exploitation and minimizes solid waste sent to landfills. Automation and robotization have also significantly improved workers' conditions by reducing their direct exposure to heat and dust, enhancing workplace safety, and improving operational discipline.

Regarding economic and financial performance, the over 80 billion VND investment in the mobile tunnel kiln and closed-loop production line is offset by several factors: (i) a 30% increase in output compared to the old line; (ii) lower fuel and electricity costs due to higher thermal efficiency and automation; (iii) a substantial reduction in direct labor costs as robots replaced about 40 workers; and (iv) a lower defect rate, leading to improved product quality, consistency, and ultimately higher profit margins and price competitiveness.

In summary, this is a classic case of technological innovation in brick manufacturing, transitioning from traditional kilns to modern tunnel kilns. It effectively aligns with the goals of saving energy, reducing emissions, and shifting towards a greener production model within the building materials industry.

Table 15. . Summary of information on the mobile tunnel kiln investment case study

Category	Unit	Value
Technology before investment	–	Traditional Hoffmann kiln for brick firing
Technology after investment	–	Mobile Tunnel Kiln (Humpback kiln), closed-loop production line with robots
Investment cost	Billion VND	> 80
Design capacity	Million bricks/year	30
Change in production output	%	+30%
Change in labor	People	Reduction of ~40 direct laborers
Primary Fuel	–	Fine coal
Specific coal consumption before investment (hoffmann kiln – assumed)	kg coal / 1,000 bricks	200
Specific coal consumption after investment (tunnel kiln – assumed)	kg coal / 1,000 bricks	135
Total coal consumption before investment	tons/year	≈ 6,000
Total coal consumption after investment	tons/year	≈ 4,050
Coal saved annually	tons/year	≈ 1,950
Reference coal price	VND/kg	2,000
Annual fuel cost savings	Billion VND/year	≈ 3.9
CO ₂ emission factor for type 3–5 fine coal	tCO ₂ /ton coal	2.1 – 2.9
Estimated annual CO ₂ emission reduction	tCO ₂ /year	≈ 5,600
Simple payback period – based on coal savings only	Years	≈ 20–21

3.2 International case studies

3.2.1 Regenerative burners for steel reheating kiln (Thailand)

3.2.1.1 Regenerative burners for steel reheating kiln (Thailand)

A steel rolling mill in Thailand operates a hot rolling line using a pusher-type slab reheating kiln with a capacity of approximately 30 tons of steel slabs per hour.

The kiln uses natural gas fuel, with an internal heating temperature of about 1,100–1,250°C, operating nearly continuously to supply heated slabs to the rolling line.

Before the retrofit, the kiln was already equipped with a recuperator heat recovery unit to utilize waste heat from exhaust gases for preheating combustion air. However, due to heat exchange limitations, the preheated air temperature only reached approximately 300°C, while the exhaust gas temperature remained high, indicating significant heat losses. The specific energy consumption per ton of rolled steel was still quite high, fuel costs were a substantial component of product cost, and corresponding CO₂ emissions were a concern.

To enhance energy efficiency, the plant decided to invest in a regenerative burner system, combined with an upgrade of the control & instrumentation system and optimization of the kiln operating regime.

3.2.1.3 Description of the energy efficiency solution

The implemented solution involved replacing conventional burners with regenerative burner sets. Each set consists of two symmetrically mounted burners paired with a chamber containing a honeycomb refractory brick regenerator. The working principle is as follows:

- » In one cycle, one burner operates, drawing combustion air through the preheated regenerator chamber; the air is heated from ambient temperature to approximately 1,000°C before entering the combustion chamber.
- » Simultaneously, the paired burner operates in exhaust mode; hot flue gases from the kiln flow in reverse through its refractory brick mass, transferring heat and warming the bricks.
- » After a set period (several seconds to minutes, depending on design), the cycle reverses: the firing burner switches to exhaust mode, and the other burner begins supplying fuel and air, which is preheated by its now-hot regenerator bricks.

Through this alternating heat recovery process, the pre-combustion air temperature increases significantly (to approx. 1,000°C), which translates into a substantial reduction in the fuel required to achieve the kiln's heating temperature. The system was integrated with:

- » A PLC/DCS control system to manage the cycle reversal, gas/air flow rates, and kiln pressure.
- » A monitoring system for kiln zone temperatures, combustion air temperature, flue gas temperature after the regenerator, and stack temperature.

- » Explosion safety equipment, fast-closing valves, pressure sensors, and emergency vent valves.

The entire retrofit was carried out during a scheduled maintenance shutdown to minimize production downtime.

3.2.1.4 Energy, environmental, and financial performance

Pre- and post-retrofit measurements showed:

- » Combustion air temperature increased from ~300°C (with recuperator only) to nearly 1,000°C with the regenerative burners.
- » The kiln's specific fuel consumption was reduced by approximately 43% compared to using only the recuperator, while maintaining the same output and product quality.
- » The final exhaust gas temperature after the heat recovery system decreased significantly, sharply reducing flue gas heat losses.
- » CO₂ emissions from natural gas consumption were reduced correspondingly (~0.2 tCO₂/MWh thermal), contributing to the company's emission reduction targets.

Financially, while detailed capital investment figures were not fully disclosed, international experience indicates:

- » For medium to large kilns, a typical payback period is around 2–4 years, depending on fuel prices and the existing level of heat recovery.
- » The fuel savings cash flow is relatively stable, facilitating access to green financing or implementation under ESCO models.

Additionally, thanks to improved heat distribution and better combustion control, some plants also reported:

- » A slight increase in rolling mill productivity due to reduced heating time.
- » Lower scrap rates caused by overheating or uneven heating.

3.2.1.5 Lessons learned and replication potential in Vietnam

Prerequisites:

- » The kiln operates continuously with medium-to-large capacity and high working temperatures (>1,050–1,100°C).
- » Availability of natural gas/LPG/controlled-quality blast kiln gas with reliable supply pressure.
- » The kiln structure has sufficient space for installing regenerative burner sets and associated ducting.

System design and integration:

- » Detailed design of burner positioning, temperature zoning, and optimized cycle reversal timing is crucial to avoid excessive kiln temperature fluctuations.
- » The retrofit should be combined with insulation upgrades, reduction of cold air in-leakage, and optimization of the product path.

Operation and maintenance:

- » Requires operational staff with a solid understanding of the system's working principles, especially regarding failure modes (loss of gas, power, cycle reversal valve faults).
- » The regenerator chamber needs periodic inspection for cracking, dust build-up, or blockage of refractory channels.

This regenerative burner solution is highly suitable for:

- » Slab/billet reheating kilns in long product, plate, and structural steel rolling mills.
- » Forging kilns and continuous or semi-continuous metal heat treatment kilns.
- » Other high-temperature industrial kiln and furnace system (ceramics, refractories) if using gaseous fuel and having adequate space for equipment installation.

Favorable factors in Vietnam:

- » The long product and rebar steel rolling sector has numerous reheating kilns with capacities from several tens of tons/hour upward, offering significant savings potential if burner conversion is implemented.
- » Policies promoting energy efficiency and greenhouse gas reduction enhance the attractiveness of such deep retrofit investment projects.

Key barriers:

- » Relatively high initial capital investment compared to "light" EE measures (operational optimization, insulation, fan/pump upgrades).
- » Dependence on technology providers (regenerative burners, reversal valves, control systems) and post-sales maintenance services.
- » Higher requirements for technical operational skills, necessitating training and technical support during the initial phase.

In summary, this is an in-depth energy efficiency solution for metal reheating kilns, delivering substantial reductions in energy consumption and clear impacts on production costs and CO₂ emissions. For medium and large-scale steel rolling mills in Vietnam, researching and piloting the application of regenerative burners

is a promising direction, particularly in the context of rising energy costs and increasingly stringent emission reduction requirements.

3.2.2 Retrofit of steel reheating kiln using a regenerative burner combustion system (RBCS), Indonesia

3.2.2.1 General information

Representative enterprise: PT Gunung Garuda, Cibitung, Indonesia – a model project under Indonesia-Japan cooperation (Nippon Steel Engineering, NEDO, JICA).

Typical scale: The replication program was designed for reheating kilns with capacities of approximately 300,000 tons/year (large mills) and 50,000 tons/year (medium mills). Installation involves 12 burner pairs for a large kiln and 2 burner pairs for a medium kiln.

3.2.2.2 Description of the EE technology

The original reheating kilns used conventional burners combined with metallic recuperators to partially recover waste heat from flue gases.

- » Each burner pair alternates between two modes: firing and exhaust.
- » In exhaust mode, high-temperature kiln gases pass through a ceramic regenerator bed, heating it.
- » In firing mode, combustion air is drawn through the pre-heated ceramic bed and is heated to approximately 900–1,000°C, close to the kiln temperature before mixing with fuel.

As the heat for combustion comes from deeply pre-heated air, the system:

- » Significantly reduces the fuel required for the same thermal load.
- » Reduces heat loss through exhaust gases.
- » Reduces NO_x emissions due to a "soft," low-oxygen combustion regime and uniform heat distribution within the kiln chamber.

3.2.2.3 Investment scale and performance indicators

Demonstration scale:

- » Large mill: 18 kilns, each with 12 burner pairs.
- » Medium mill: 33 kilns, each with 2 burner pairs.

Equipment investment cost:

- » ~33 billion Rupiah (~52 billion VND) for 12 burner pairs (one large kiln).
- » ~5 billion Rupiah (~8 billion VND) for 2 burner pairs (one medium kiln).

Energy and financial performance:

- » Energy savings: Approximately 30% reduction in oil/fuel consumption for reheating kilns compared to conventional burner technology.

- » Fuel cost reduction: ~300 billion Rupiah (~470 billion VND) over 10 years. Additional costs (O&M, depreciation, interest) were ~70 billion Rupiah (~110 billion VND), yielding a net benefit of 230 billion Rupiah/10 years (~360 billion VND/10 years).
- » Financial metrics: Internal Rate of Return (IRR) ~20% under a scenario with partial capital support. With high oil prices, the IRR for the enterprise alone could approach 60%.
- » Emission reduction: ~33 thousand tons CO₂/year reduction when replicated across all target kilns in the Indonesian steel industry.

3.2.2.4 Assessment of applicability in Vietnam

Technological compatibility: Vietnam has numerous steel reheating kilns (for long product and plate rolling) currently using FO (Fuel Oil) or natural gas, with operating temperatures of 1,150–1,250°C and high-temperature exhaust gases. These conditions are very similar to those of plants in Indonesia and Japan, creating an environment highly suitable for regenerative burners.

Savings potential: Assuming a reheating kiln with similar fuel consumption, a 25–30% fuel reduction is technically feasible, especially for kilns currently using conventional burners and metallic recuperators. This reduction could translate into annual fuel cost savings of tens of billions of VND for each kiln with a capacity of 200,000–300,000 tons per year, depending on the price of FO/gas.

Infrastructure & prerequisite requirements:

- » A stable fuel source (natural gas/NG, LPG, gasified coal) or consistent-quality fuel oil (FO) is required.
- » Adequate space must be available on the kiln wall for installing the ceramic regenerator units (which are typically larger than conventional burners).
- » An automated combustion control system is necessary, including fuel and air flow measurement and flue gas O₂ monitoring.
- » The refractory brick quality and kiln structure must withstand the higher local temperatures near the burner zone.

Localization potential & barriers:

- » Localization potential: For mechanical and structural components, Vietnam has the capability to manufacture burner housings, ductwork, and supports. However, the ceramic regenerator blocks and high-temperature cycle reversal valves may need to be imported initially.
- » Key barriers: The main barriers are the relatively high initial investment cost and the requirement for a kiln shutdown to execute the retrofit.

However, with a practical Internal Rate of Return (IRR) of 17–20% or higher, evaluated over a 10-year period, this solution is well-suited for energy efficiency projects supported by preferential credit lines or ESCO (Energy Service Company) models.

Recommendations for Vietnam:

- » Prioritize pilot testing on 1–2 steel billet/slab reheating kilns with a capacity of $\geq 200,000$ tons/year that currently use fuel oil (FO) or natural gas and have complete historical fuel consumption data.
- » Implement comprehensive pre- and post-retrofit measurement and verification (M&V) to build a standardized dataset on specific energy consumption, costs, and emissions. This data can then be used to include this technology in the official list of recommended Energy Efficiency (EE) technologies for the steel industry and other high-temperature industrial kiln and furnace system in general.

3.2.3 Heat wheel for heat recovery in ceramic tunnel kilns (India)

3.2.3.1 Background and current technology status

This ceramics enterprise operates a tunnel kiln fired by fossil fuel (typically oil or gas) for firing ceramic and porcelain products. The typical kiln configuration consists of zones for drying, preheating, firing, and cooling. Prior to the retrofit, the preheating zone discharged approximately 7,500 m³/h of hot gas at 300°C directly into the environment, while the kiln's input end required a supply of hot air for product drying and preheating.

This situation led to two major problems:

- » Significant heat loss through the exhaust stream, resulting in high fuel consumption per unit of product and making energy costs a substantial portion of the production cost.
- » Limited temperature of the air supplied to the drying/loading zone at the kiln's entrance, affecting drying rates and increasing the risk of product cracking or breakage if control was inadequate.

The company's objectives were to reduce fuel costs and utilize waste heat without excessively complicating kiln operation. Therefore, they opted to install a heat wheel in the preheating zone.

3.2.3.2 Detailed description of the heat wheel solution

A heat wheel is a type of rotary regenerator (rotary heat exchanger) suitable for low to medium temperature ranges. The wheel is constructed from a material with high heat capacity (such as stainless steel, ceramic honeycomb material, etc.), featuring a porous structure with numerous small channels for gas passage.

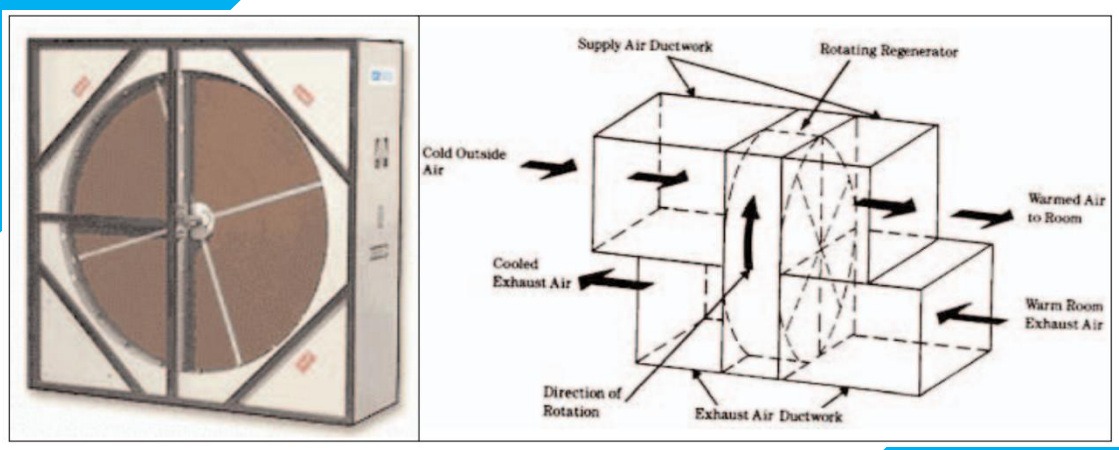


Figure 24. Schematic diagram of the heat wheel

The installation works as follows:

- » The 300°C hot gas stream from the preheating zone passes through one half of the wheel's cross-section and is then discharged to the stack.
- » The remaining part of the rotating wheel moves to the fresh air stream (taken from the kiln top or the environment), transferring its stored heat to this air before it is supplied back to the drying/preheating zone.
- » The wheel rotates continuously at a low speed (a few revolutions per hour), ensuring that each material element alternately contacts the hot gas and the cold air.

This structure gives the device several advantages:

- » A very large heat transfer surface area within a small volume, low pressure drop, suitable for high-volume gas flows like tunnel kiln exhaust.
- » Can handle temperature ranges up to approximately 300–350°C, which aligns with the exhaust gas temperatures from the drying/preheating zones in the ceramics industry.

A simple drive system (one low-speed motor) makes operation and maintenance convenient.

3.2.3.3 Results and performance indicators ¹

- » Exhaust gas temperature after the heat wheel decreased from 300°C to approximately 150°C.
- » Fresh air was preheated to about 155°C before being supplied to the drying/preheating zone.

¹ Bureau of Energy Efficiency (BEE). *Energy Efficiency in Thermal Utilities – Chapter 8: Waste Heat Recovery*. New Delhi, India. Case example: heat wheel installed on tunnel kiln in ceramic industry.

- » The dedicated burner for hot air in this zone became unnecessary, as the heat for drying/preheating was almost entirely supplied by waste heat.
- » The investment payback period was less than 12 months, thanks to significant fuel savings.

The solution reduces the exhaust stream temperature by 150°C for a flow of 7,500 m³/h; simultaneously, it completely replaces the energy requirement for a burner zone, indicating that the amount of recovered heat is substantial, especially considering that tunnel kilns operate continuously across multiple shifts per year.

Environmentally, reduced waste heat directly translates to: decreased fossil fuel consumption, and consequently, reduced CO₂ and other pollutant emissions (NO_x, SO₂) accordingly.

Beyond energy efficiency, the enterprise also benefited in product quality: the drying air had a more stable temperature, humidity was better controlled, reducing the risk of product cracking or deformation during the drying stage.

3.2.3.4 Assessment of applicability and replication potential in Vietnam

This solution is particularly suitable for:

- » Medium and large-scale tunnel kilns for bricks, tiles, ceramics, and sanitary ware operating in Vietnam.
- » Kilns where the drying/preheating zone discharges a continuous stream of hot gas at 250–350°C, while the kiln inlet requires hot air or primary combustion air.

In many current plants, exhaust gases from drying/preheating zones still have relatively high temperatures and are either released directly into the environment or only partially utilized by simple heat exchange pipes. Replacing these with a heat wheel can significantly increase the depth of heat recovery without fundamentally altering the kiln structure.

3.2.3.5 Technical risks and design considerations

Key risks for application in Vietnam include:

- » Dust accumulation, glaze deposition, and corrosion on the wheel surface due to particulates and chemical vapors in the exhaust gas.
- » Gas leakage from the hot side to the fresh air side if the sealing system design is poor, which could contaminate the supply air or disrupt the kiln's pressure balance.
- » Increased system resistance, potentially necessitating upgrades to the induced/forced draft fans if not properly calculated beforehand.

To mitigate these risks, the design must:

- » Select appropriate wheel materials (dust-resistant, corrosion-resistant) and arrange for periodic self-cleaning or jet cleaning systems.
- » Design a bypass zone to allow the heat wheel to be isolated from the gas stream during certain operating modes (e.g., maintenance, low production, or when exhaust conditions change).
- » Conduct an overall thermal and pressure balance calculation for the entire kiln system to ensure it does not adversely affect the combustion regime and temperature profile along the kiln length.

3.2.3.6 Financial feasibility in Vietnam

Given the typical payback period of under 1 year in the Indian case study, the payback period in Vietnam can be expected to be within 1–2 years, depending on:

- » Fuel prices (fine coal, oil, LPG, or gas),
- » The number of operating hours per year for the kiln,
- » The equipment investment and installation costs.

This represents a relatively "light" investment compared to building a new kiln or completely changing the technology. It is highly suitable for inclusion in the list of recommended Energy Efficiency (EE) solutions for the brick & tile, ceramics, and sanitary ware industry clusters.

3.2.4 Oxy-fuel glass melting kiln with electric boosting (Şişecam – Turkey)

3.2.4.1 Background and current technology status

In fiberglass production, requirements for high temperature, uniform heat distribution, and sufficient residence time within the glass bath are extremely stringent to ensure fiber strength, homogeneity, and drawing capability. The Şişecam fiberglass kiln in this study is a unit melter operating on oxy-fuel combustion, equipped with 9 flat-flame burners installed in the combustion chamber.

Oxy-fuel combustion significantly reduces NO_x and dust emissions compared to air-fuel kilns. However, it increases the tendency to form a foam layer on the surface of the molten glass. This insulating foam layer reduces heat transfer from the combustion zone to the glass bath, creating a limit when trying to increase kiln pull rate.

Simultaneously, market demand required a kiln capacity increase of approximately 25–30% while maintaining fiberglass quality (homogeneity, low bubble content). Therefore, the company's objectives were:

- » To increase the pull rate (glass pulling speed) by about 28%;

- » To maintain or improve glass quality;
- » To reduce specific fuel gas consumption and its associated emissions.

3.2.4.2 Detailed description of the solution: Oxy-Fuel + Electric Boosting + Bubblers

Şişecam's research implemented two solution groups simultaneously in the oxy-fuel fiberglass kiln:

Multi-zone electric boosting system

- » The kiln was equipped with 4 electric boosting zones, each with 6 bottom electrodes in the glass bath (totaling 24 electrodes).
- » Maximum electrode power was approximately 1,700 kW (Case 5 in the model).
- » Power distribution: About 53% of the electrical energy was allocated under the batch charging zone, and 47% under the hot spot zone. This aimed to both increase the initial melting temperature and maintain high temperature in the refining zone.
- » The system was designed based on a 3D mathematical model of the kiln to optimize convection currents, temperature fields, and glass residence time.

Bubbler system in the glass bath

- » Two rows of bubblers were positioned at about 70% of the kiln length from the outlet, spanning the width of the glass bath.
- » The bubblers' task is to create a stream of bubbles rising from the bottom to the surface, pulling colder glass from the bottom upwards. This increases convection, thereby enhancing heat exchange between the combustion zone and the glass, as well as within the molten glass mass itself.

How it works synergistically:

- » Electric boosting delivers energy directly into the glass mass with very high efficiency (80–90%), increasing the bottom temperature, activating stronger convection currents, and shortening the melting–refining time.
- » Bubblers further reinforce convection, especially around the hot spot, creating two main circulation loops within the glass bath. This helps distribute heat more evenly, increases glass homogeneity, and assists in foam reduction.

The solution was investigated through 5 scenarios with progressively increasing electrical power and different bubbler configurations, after which the optimal configuration was selected for practical implementation.

3.2.4.3 Results and key performance indicators²

Increased capacity and product quality:

- » Auxiliary electric heating allows the pull rate to be increased from 1.60 to 2.0 tons/m²-day, equivalent to increasing kiln capacity by approximately 25–28% while still ensuring the required glass quality standards.
- » The model showed that convection currents within the bath were enhanced, and residence time and temperature distribution became more favorable for the refining and bubble removal processes, contributing to stable fiberglass quality.

Fuel gas savings and energy efficiency:

- » When replacing a portion of the energy from gas with electricity, the specific gas fuel consumption decreases by approximately 15%, reflecting the reduction in specific fuel consumption as the proportion of electricity in the total energy supplied to the kiln increases.
- » At the same time, oxy-fuel combustion technology helps reduce the volume of exhaust gas requiring treatment and lowers emissions of NO_x, SO₂, and particulates compared to kilns using air as the oxidant.

Impact of bubblers and kiln temperature:

- » In the scenario with maximum electrode power (approximately 1,700 kW) and the bubblers system activated, the average temperature of the glass bath increases by about 35°C compared to the case without using the aeration system.
- » The bubblers system raises the bottom temperature and improves temperature uniformity along the depth of the bath. This enhances heat exchange efficiency, reduces "cold" zones within the bath, contributes to lower defect rates, and supports faster color/ composition changes.

Economic and operational aspects:

- » The optimal amount of supplementary electricity is determined by comparing the relative costs of electricity and oxygen/fuel, with the goal of minimizing the total energy cost per ton of product while still achieving the capacity increase target.
- » From a technical perspective, reducing part of the heat load from the combustion zone (due to electrical assistance) can help lower the crown temperature of the kiln, thereby extending the lifespan of the refractory materials.

² Durubal, M., Gül, B. A Numerical Investigation of the Effect of Electric Boosting in an Oxy Fuel Fired Glass Fiber Kiln. Şişecam Science and Technology Center, Gebze, Turkey, Glass Service seminar paper

3.2.4.4 Assessment of applicability and replication potential in Vietnam

Potential target entities:

- » New glass melting kiln construction projects (for architectural glass, solar glass, ultra-clear glass, and fiberglass) are considering the application of oxy-fuel combustion technology or a hybrid solution combining oxy-fuel combustion with auxiliary electric heating.
- » Manufacturing plants with competitive industrial electricity prices relative to gas/oil fuel prices and facing pressure to reduce CO₂, NO_x, and dust emissions.

Prerequisite conditions:

- » Access to a stable industrial oxygen supply at a reasonable cost (onsite production or external procurement).
- » A robust, high-capacity power supply and distribution system to ensure continuous electricity for the electrodes; risks of power loss and associated safety protocols must be considered.
- » A skilled technical team with experience operating oxy-fuel kilns, electrodes, and bubblers, supported by a monitoring and control system for temperature and convection currents using models and/or online measurement equipment.

Expected benefits for Vietnam:

- » If applied similarly, medium to large-scale glass kilns could increase capacity by 20–30% without building a new kiln, while simultaneously reducing specific gas fuel consumption by 10–15%, and lowering CO₂ and other pollutant emissions per unit of product.
- » Coupled with green credit mechanisms, carbon certificates, or incentives for emission reduction projects, the financial viability could become more attractive, despite the high initial capital investment.

Key barriers:

- » High initial investment cost, including the system for producing or importing oxygen, electrodes, transformers, control systems, and exhaust gas treatment equipment suitable for oxy-fuel combustion mode.
- » Dependence on the price correlation between electricity and gas/fuel oil: in the case of high electricity prices, the approximately 15% reduction in gas consumption may not be sufficient to offset the additional electricity costs.

In summary, the Şişecam case demonstrates that an oxy-fuel kiln combined with electric boosting and bubblers is an advanced technological solution that

simultaneously increases capacity, reduces fossil fuel demand, and improves glass quality. This serves as an important reference model when developing the list of recommended Energy Efficiency (EE) technologies for new-technology glass kilns or deep transformation projects aimed at emission reduction in Vietnam's glass industry.

CHAPTER 4. LIST OF TECHNOLOGY PROVIDERS

4.1 Domestic providers

Industrial kiln technology has been designed, manufactured, and supplied by many Vietnamese enterprises to industries such as ceramics & construction materials, metallurgy & mechanical engineering, chemicals, agricultural & food processing, waste treatment, and energy. The majority of domestic manufacturers currently focus on the small and medium-capacity kiln segment. However, some have gradually approached larger-scale kiln projects, integrating heat recovery systems, automated controls, and solutions for energy savings and emission reduction.

The list of domestic industrial kiln providers participating in the survey can be divided into three main groups:

Group 1: Enterprises specializing in the comprehensive design and manufacture of industrial kiln and furnace system:

These entities provide various kiln types, including: rotary kilns, tunnel kilns, shuttle kilns, roller hearth kilns, chamber kilns, resistance kilns, arc kilns, non-ferrous metal melting kilns, combined drying-firing kilns for ceramics and construction materials, biomass burners, solid waste incinerators, spray dryers, and other specialized kilns. Most of these units have mastered thermal-gas design, mechanical design, and installation, and possess the capability to optimize kiln shell structure, refractory, and insulation materials to reduce heat loss.

Group 2: Enterprises supplying equipment, spare parts, and auxiliary systems for kilns:

This group includes suppliers of refractory materials (refractory bricks, castables, ceramic fiber, board/tube insulation), oil/gas burners and biomass combustion chambers, fans & air supply systems, flue gas heat recovery units, heat exchangers, as well as control & instrumentation solutions (control panels, PLCs, monitoring and data logging systems for temperature, pressure, and flow). Many providers in this group are deeply involved in the retrofit and upgrade of existing kilns, focusing on energy savings and reducing dust and gas emissions.

Group 3: Consulting firms, EPC contractors, and technical service providers:

These organizations perform basic and detailed engineering design, develop investment project proposals, act as turnkey contractors for supplying and installing kilns and auxiliary systems, conduct commissioning tests, provide operational training, offer periodic maintenance services, and perform energy performance assessments and retrofit solution proposals.

Detailed information on each domestic provider, compiled from survey forms and interviews, is presented in an accompanying data table with the following key fields: company name, address, contact phone number, email, type of technology/services provided,....

In addition to kiln manufacturers, the list of domestic providers also includes several suppliers of refractory materials, thermal support equipment (electric heaters, heat exchangers, waste heat recovery units), and combustion & control systems. These entities play a crucial role in upgrading existing kilns, particularly by replacing refractory materials, retrofitting burners, installing VFDs (Variable Frequency Drives) for fans, and adding heat recovery units, thereby improving overall performance and extending equipment lifespan.

The overview indicates that domestic providers are currently capable of adequately meeting the demand for new investment and retrofitting of small and medium-scale industrial kiln and furnace system. They achieve a high level of localization for mechanical structures, refractory materials, and construction/installation. For large-scale projects, those requiring complex technology, or strict environmental and safety standards, many enterprises have proactively collaborated with foreign licensors or technology providers. This cooperation involves adopting designs and selecting core equipment (such as high-capacity burners, advanced control systems, and flue gas treatment equipment), while still leveraging domestic advantages in labor, fabrication, and after-sales services. This forms a crucial foundation for promoting the development of energy-efficient, low-emission industrial kiln solutions in Vietnam in the coming period.

Table 16. List of domestic industrial kiln technology suppliers

No.	Supplier Name	Address	Phone Number	Email	Website	Technology/Service Provided
1	AMECO Joint Stock Company	CC2, 5th Floor, New Skyline Commercial Center, Văn Quán – Yên Phúc Urban Area, Hà Đông Ward, Hanoi.	0986 882 993	contact@amecojsc.com	https://amecojsc.com/	Industrial kiln and furnace system, industrial dryers
2	Hokuriku Machine Joint Stock Company	Cổ Điển Village, Vĩnh Thanh Commune, Hanoi	0243 525 1117	sales.as.hn@hmc-c.com	https://hmc-c.com/	Multi-purpose/multi-fuel industrial kiln and furnace system
3	TDH Industrial Equipment Trading and Manufacturing Joint Stock Company	Lot 1, Block 4, Lai Xá Industrial Cluster, Hoài Đức Commune, Hanoi City	0967 469 838	quangbt@tdhvietnam.com	https://thietbiloconghiep.com/	Industrial heating kilns, thermal kilns
4	CMS Co., Ltd.	An Lạc Village - Trưng Trắc - Văn Lâm - Hưng Yên	083 678 1978	sales@cms-machinery.vn	https://cms-machinery.vn/	Quenching, high-frequency heating kilns
5	Việt Trung Technology and Trading Co., Ltd.	Long Thành Intersection - Km 87 - New Road - Cách Thượng - Nam Sơn - An Dương - Hai Phong City	0912 810 179	congngheviettrung@gmail.com	http://congngheviettrung.vn/	Medium-frequency steel smelting kilns, high-frequency quenching kilns, cooling towers, furnace parts & supplies, continuous casting machines, furnace transformers, water cooling towers, furnace parts & supplies.
6	EroHome Co., Ltd.	No. 12 BT 9, Vân Canh New Urban Area, Hoài Đức, Hanoi	082 905 1111	erohome18@gmail.com	https://maylonungcotan.com/	High-frequency and medium-frequency heating kilns

No.	Supplier Name	Address	Phone Number	Email	Website	Technology/Service Provided
7	VITCOM One Member Co., Ltd.	No. 3, Alley 69, Lane 117 Thái Hà, Trung Liệt Ward, Đống Đa District, Hanoi City	2.422.455.500	sale@vitcom.vn	https://www.vitcom.vn/	Aluminum melting kilns, aluminum casting
8	Hưng Long International Co., Ltd.	No. 22, Lane 274 Nguyễn Lân Street, Phương Liệt Ward, Thanh Xuân District, Hanoi.	0904 145 850	maygianhiet@gmail.com	https://lonungtrungtan.com/	Medium-frequency heating kilns
9	Minh Sơn Mechanical Manufacturing Co., Ltd.	No. 28 Tam Trinh, Yên Sở Ward, Hoàng Mai District, Hanoi	Director Trần Ngọc Khánh: 0985 987 898	khanhtientamchinh@gmail.com	x	Heating Kilns - Heat Treatment Kilns - Industrial kiln and furnace system
10	Hoàng Kim Manufacturing Co., Ltd.	No. 81, Đại Đồng Street, Thanh Trì Ward, Hoàng Mai District, Hanoi	091 208 6984	giaho.ceo@gmail.com	https://maynganhnhua.com.vn/	Heating, quenching, tempering, annealing kilns
11	Việt Phát Industrial Equipment Co., Ltd.	No. 39, Alley 281 Đội Cấn, Liễu Giai Ward, Ba Đình District, Hanoi	915456256	sales@congnghievietphat.com.vn	https://www.cokhivietphat.com/	High-frequency kilns
12	Dần Nguyệt Trading Co., Ltd.	30 Lán Bè, Lam Sơn Ward, Lê Chân District, Hai Phong City	0913 516 291	dannguyet.ltd@gmail.com	https://dannguyetltd.com/	Medium-frequency heating kilns, High-frequency kilns
13	Bình An Technology Trading & Engineering Co., Ltd.	No. 1, Alley 214 Hoàng Mai, Hoàng Văn Thụ Ward, Hoàng Mai District, Hanoi City, Vietnam	0962 373 889	sale.cnba@gmail.com	congnghebinhan.com.vn	Heating kilns

No.	Supplier Name	Address	Phone Number	Email	Website	Technology/Service Provided
14	Hoàng Kim Aluminum Design Consulting and Construction Co., Ltd.	No. 26-Alley 3-Lane 4 Cầu Bươu - Tả Thanh Oai Commune- Thanh Trì District- Hanoi City	0982 783 143	hoangkimalum@gmail.com	https://hoangkimalum.com/	Aluminum melting kilns
15	Văn Minh Co., Ltd.	55 Phùng Hưng – Hoàn Kiếm - Hanoi	(+84) 243 9271027 - 9271028 – 9272900	sales-hn@vanminh.com.vn	https://vanminh.com.vn/	Nabertherm Kilns
16	Khắc Nguyễn Manufacturing and Trading Joint Stock Company	No. 21, Street 18, Linh Chiểu Ward, Thủ Đức District, Ho Chi Minh City	903.041.056	lonung@khaconguyen.com	https://khaconguyen.com/	Manufacture of heating, quenching, tempering, annealing kilns
17	Kha Vy Technology Co., Ltd.	295/25/11A Tân Hòa Đông, Bình Trị Đông Ward, Ho Chi Minh City	0933 899 660	khavy.2017@gmail.com	https://khavy.com.vn/	Medium and high-frequency kilns
18	Đại Đồng Phát Co., Ltd.	27A, Hamlet 3A, Phước Lợi Commune, Bến Lức District, Long An Province	09822 33 040	dadopha123@gmail.com	http://www.daidongphat.com.vn/	Metal melting, heating, annealing kilns
19	FOUNDRY Vietnam Investment Co., Ltd.	No. 02 Độc Lập Avenue, An Bình Ward, Ho Chi Minh City	0904 320 831	info@fovina.com.vn	https://fovina.com.vn/	Metal (aluminum, Mg, Zn) melting, annealing kilns
20	Việt Nhật Heating Furnace Co., Ltd.	19Z2 Nguyễn Hữu Cảnh, Ward 19, Bình Thạnh District, Ho Chi Minh City	028 38405458	support_vina@vietnhat-furnace.com	https://vi.nc-net.com/company/88003/	Refractory bricks, industrial kiln and furnace system

No.	Supplier Name	Address	Phone Number	Email	Website	Technology/Service Provided
21	Trường Tín Furnace Co., Ltd.	2nd Floor, Room 2.23, Charmington La Pointe Building, 181 Extended Cao Thắng, Ward 12, District 10, Ho Chi Minh City	0903 101 032 (028) 36366192	tai@lotruongtin.com	http://lotruongtin.com/	Aluminum/copper gas pot kilns, Aluminum/copper electric pot kilns, Aluminum/copper ben pot kilns, Aluminum melting and holding furnaces
22	K.E.N.U.O One Member Co., Ltd.	Land Plot No. 286, Map Sheet No. 15, Khánh Long Quarter - Tân Phước Khánh Ward - Tân Uyên Town - Bình Dương	0327880761 0949827087	nguyenhoangbaoxuyen8787@gmail.com	http://www.kenuo.com.vn/	Melting kilns, electric heating kilns, medium-frequency melting kilns, metal melting kilns
23	Hùng Dũng Heating Furnace One Member Co., Ltd.	Group 3, Phước Thái Quarter, Thái Hòa Ward – Tân Uyên Town - Bình Dương	0938 990 820	cungcaplonung@gmail.com	https://cungcaplonung.com/	Electric resistance heating kilns, steel annealing kilns, drying kilns
24	Sài Gòn Xuân Nguyên One Member Co., Ltd.	252/4/36 National Highway 1A, Bình Hưng Hòa B Ward, Bình Tân District, Ho Chi Minh City	0903 876 596 0961 433 988	thietbihanxuannguyen@gmail.com	https://thietbihan.net/	High-frequency heating machines
25	HMT Industrial Equipment Trading and Service One Member Co., Ltd.	55/6C Đông Tác Quarter, Tân Đông Hiệp Ward, Dĩ An City, Bình Dương Province, Vietnam	0909 674 179 (028) 37367302	tuyencokhi@gmail.com	https://thietbilonung.com/category/lo-cong-nghiep/	Electric resistance heating kilns, gas/electric resistance/oil melting kilns
26	Nagamochi Co., Ltd.	13/1R XTT30 Street, Hamlet 28, Bà Điểm Commune, Ho Chi Minh City	0934 479 853	Nagaco2018@gmail.com	https://naga-c.com/	Metallurgical furnace industry: aluminum & copper, drying kilns, annealing kilns,

No.	Supplier Name	Address	Phone Number	Email	Website	Technology/Service Provided
						graphite crucibles, refractory & insulating bricks/castables, heating elements, ceramic fiber blankets, and other furnace components.
27	Phước Lộc Mechanical Manufacturing, Trading, and Service Co., Ltd.	94/6 Group 10, KP2 Nguyễn Văn Quá, Đông Hưng Thuận Ward, District 12, Ho Chi Minh City	0973 870 279	chetaomayphuocloc@gmail.com	https://chetaomayphuocloc.com/	High-Frequency Heating Kilns - Heat Treatment Kilns - Industrial kiln and furnace system
28	Việt Đài Heating Element Manufacturing and Trading Co., Ltd.	24/13 TL 27 Street, Quarter 3C, Thạnh Lộc Ward, District 12	0987 252 886	hoangdientro@gmail.com	https://dientrovietaidai.com/	Heating, annealing, metal melting kilns
29	Mặt Trời Xanh Manufacturing, Trading, and Service Co., Ltd.	31 Street 156, Hamlet 6A, Bình Mỹ Commune, Củ Chi District	0986 185 832	vinagreensun@gmail.com	https://vinagreensun.com/	High-Frequency Heating Kilns - Heat Treatment Kilns - Industrial kiln and furnace system
30	Phong Đạt Equipment and Trading Co., Ltd.	175/51 PHỐ CƠ ĐIỀU - Ward 06 - District 11 - Ho Chi Minh City	0913.772.019 0906.841.474	phongdat2404@gmail.com	https://thietbiphongdat.com/thiet-bi/	Heating Kilns, Metal Melting and Smelting Kilns
31	An Phát Construction Materials and Equipment Joint Stock Company	Hanoi: CC2, 2nd Floor, New Skyline Commercial Center, Văn Quán Urban Area, Hà Đông District, Hanoi. HCMC: No. 5, Street 12, Linh Trung Ward, Thủ Đức District, Ho Chi Minh City.	024.7108.8596 Hotline: 0986 882 993 0987 821 819	contact@amecojsc.com	https://amecojsc.com/	Electric Furnaces, Gas-fired Kilns, Oil-fired Kilns

No.	Supplier Name	Address	Phone Number	Email	Website	Technology/Service Provided
32	WanTai Precision Machinery Co., Ltd.	Lot T50, Kiều Ky Craft Village Production Cluster, Gia Lâm District, Hanoi City 111 Mã Lò, Bình Trị Đông A Ward, Bình Tân District.	0935 787 698 0903 988 934 024 62968606	cokhiwantai@gmail.com	https://cokhiwantai.com/	IGBT frequency quenching and heating kilns
33	Phước Lộc Mechanical Manufacturing, Trading, and Service Co., Ltd.	94/6 Group 10, KP2 Nguyễn Văn Quá, Đông Hưng Thuận Ward, District 12, Ho Chi Minh City Northern Branch: Tiến Lộc, Hậu Lộc - Thanh Hóa	0369 580 596	chetaomayphuocloc@gmail.com	https://chetaomayphuocloc.com/	High-Frequency Heating Kilns - Heat Treatment Kilns - Industrial kiln and furnace system

The overview indicates that domestic suppliers can currently meet the demand for new investment and retrofitting of small to medium-scale industrial kiln and furnace system effectively, with a high level of localization for mechanical structures, refractory materials, and construction/installation services. For large-scale projects, those requiring complex technology, or those with stringent environmental and safety standards, many enterprises are proactively collaborating with international licensors or foreign suppliers to acquire design expertise and select core equipment (e.g., high-capacity burners, advanced control systems, flue gas treatment equipment). This collaboration allows them to leverage domestic advantages in labor, manufacturing, fabrication, and after-sales services. This foundation is crucial for promoting the development of energy-efficient, low-emission industrial kiln solutions in Vietnam in the coming period.

4.2 International suppliers

International suppliers primarily originate from countries with developed heavy industries such as Germany, Japan, China, South Korea, Thailand, and other European nations. These companies typically possess advanced industrial kiln technologies, offering a high degree of automation and integrated solutions encompassing control and monitoring systems, heat recovery, and flue gas treatment. Their technologies are widely applied in sectors like cement, iron and steel, chemicals, waste treatment, ceramics/construction materials, and Waste-to-Energy (WtE).

In the Vietnamese market, most international suppliers operate through networks of agents, representative offices, or technology transfer agreements with domestic manufacturers and EPC contractors. Some have established branch offices or technical service centers in major industrial zones, thereby reducing the time for spare parts supply, maintenance services, and after-sales technical support. In general, kiln solutions from international suppliers involve a higher initial investment cost compared to domestic products, but they offer high thermal efficiency, long equipment lifespan, and comprehensive safety and environmental solutions. This makes them suitable for large-scale projects or those with stringent emission requirements.

A list of international suppliers surveyed is summarized and presented in the accompanying data table, including the following key information fields:

- » Company name and country of origin, email, website,...;
- » Primary kiln types or technologies supplied: e.g., biomass fluidized bed kilns, alternative fuel (RDF/SRF) rotary kilns, electric arc kilns, induction

kilns, high-capacity tunnel kilns, hazardous waste incinerators, specialized drying/calcination kilns, etc.

Detailed information for each international supplier (company name, core technology, technical/energy specifications, supply model in Vietnam, and project examples) is provided in the table. This serves as a reference for comparison and selection of suitable solutions during feasibility studies and investment projects for industrial kiln and furnace system in Vietnam.

Table 17. List of international industrial kiln technology suppliers

No.	Supplier Name	Phone	Email	Website	Technology type provided	Technology group
1	CEC Kilns	800 486 6836		https://ceckilns.com/	Roller hearth, pusher, batch, retort kilns	Kilns for materials, Heat treatment kilns
2	Industrial Kiln Company (IFCO)	1-800-394	help@helleries.com	https://www.industrialkiln.com/	Multiple-hearth, fluidized bed incinerator	Hybrid/multifuel kilns
3	International Thermal Systems	877-683-6797		https://www.internationalthermalsystems.com/	Box, car bottom, drop bottom, quench kilns	Heat treatment kilns
4	CAN-ENG Kilns	1 905 356 1327		https://www.can-eng.com/	Batch & continuous steel/aluminum kilns	Melting kilns
5	Ipsen International	+1 800 727 7625		https://ipsenglobal.com/	Vacuum, atmosphere, pusher kilns	Heat treatment kilns
6	ECM Technologies	+33 (0)4 76 49 65 60	info@ecmtech.fr	https://www.ecm-fours-industriels.fr/	Low-pressure carburizing, vacuum, induction kilns	Heat treatment kilns
7	ABP Induction	+86 21 5639 1278		https://abpinduction.com/en/	Induction melting kilns	Melting kilns
8	Fives Group			https://www.fivesgroup.com/	Kilns, industrial combustion systems	Hybrid/multifuel kilns
9	Andritz AG	+43 316 6902 0	welcome@andritz.com	https://www.andritz.com/group-en	Biomass, sludge and waste	Hybrid/multifuel kilns,

					incineration systems	Flue gas incinerators
10	Nabertherm GmbH	+49 4298 922-0	contact@nabertherm.de	https://nabertherm.com/en	Lab and industrial kiln and furnace system and kilns	Lab kilns
11	Ebner Industrieofenbau	(+43) 732 / 6868	office(at)ebner.cc	https://www.ebner.cc/en/welcome	Aluminum and steel heat treatment kilns	Heat treatment kilns
12	Danieli	(39) 0432.1958111		https://www.danieli.com/	Metallurgical kilns, reheat, EAF, LF	Melting kilns
13	John Cockerill	+32 4 330 24 44	welcome@johncockerill.com	https://johncockerill.com/en/	Heat recovery, combustion, boilers	Hybrid/multifuel kilns
14	ISGEC			https://www.isgrec.com/	Industrial boilers, waste heat recovery systems	Hybrid/multifuel kilns
15	FLSmidth	+45 3618 1000		https://fls.com/en	Cement kilns and rotary kilns	Kilns for materials
16	Polysius (Thyssenkrupp)			https://www.thyssenkrupp-polysius.com/en	Kilns, clinker coolers	Kilns for materials
17	Surface Combustion	800-537-8980		https://www.surfacecombustion.com/	Atmosphere kilns	Hybrid/multifuel kilns
18	Nutec Bickley	+1 (873) 498 1203		https://www.nutecbickley.com/	Kilns for ceramics, metals	Kilns for materials, Melting kilns
19	Lucifer Kilns	(215) 343-0411	info@luciferkilns.com	https://www.luciferkilns.com/	Small and mid-sized heat treatment kilns	Heat treatment kilns
20	Harper International	716-276-9900		https://www.harperintl.com/	Advanced thermal processing systems	Heat treatment kilns, Flue gas incinerators
21	CM Kilns	(973) 338-6500	info@cmkilns.com	https://cmkilns.com/	High-temp laboratory kilns	Lab kilns
22	FEECO International	920-468-1000		https://feeco.com/	Rotary kilns, dryers	Industrial dryers

23	Paragon Industries	918 291 4459	info@paragonindinc.com	https://www.paragonindinc.com/	Electric kilns and heat treat ovens	Melting kilns, Heat treatment kilns
24	Soul Ceramics	+1 831 256 3248	team@soulceramics.com	https://www.soulceramics.com/	Ceramic kilns	Kilns for materials
25	Industrial Kiln & Dryer	(877) 316-6140	contact@industrialkiln.com	https://industrialkiln.com/	Rotary dryers, kilns	Industrial dryers
26	HeatTek	8.889.051.009		https://www.heattek.com/	Industrial heat treating ovens	Industrial dryers
27	MIFCO	217-446-0941	sales@mifco.com	https://mifco.com/	Melting and heat treat kilns	Heat treatment kilns
28	Kiln Source	866-620-8417		https://www.kilnparts.com/	Vacuum, sintering, custom kilns	Heat treatment kilns, Process-specific kilns
29	Epcon Industrial Systems	9362733300	epcon@epconlp.com	https://epconlp.com/	Thermal oxidizers, ovens, kilns	Heat treatment kilns
30	Inductotherm Group	86-510-8523-1010	sales@inductotherm.com	https://inductothermgroup.com/	Induction melting and heating kilns	Melting kilns

4.3 Supplier capability assessment

After determining investment needs, preliminarily selecting the kiln type, and creating a list of potential suppliers (domestic and international), enterprises require an objective evaluation tool for comparison and selection. This catalog proposes using a supplier evaluation matrix with a scoring system. Each supplier is scored against defined criteria, which are then aggregated to establish a ranking.

Enterprises can apply a 1–5 scale for each criterion (1 = very poor/does not meet requirement, 5 = excellent/exceeds requirement). A supplier's final score can be calculated using the formula:

$$\text{Total score} = \sum (\text{Criterion Score} \times \text{Criterion Weight})$$

Here, weights (in percentage) reflect the relative importance of each criterion group for the specific project (e.g., Technology Type 30%, Experience &

Technical Capability 25%, Support Services 20%, Cost 15%, Standards 10%). Weights can be flexibly adjusted according to the requirements of different industries or projects.

The following is a suggested breakdown and scoring guide for each criterion group:

1. Technology offered

(a) Suitability for business scale (small, medium, large)

- » Score 5: Has distinct product(s)/product lines clearly designed for the enterprise's scale segment, with multiple similar projects.
- » Score 3: Can supply but requires significant adjustment/redesign.
- » Score 1: Technology is oriented towards a different scale; has few or no similar projects.

(b) Ability to supply diverse kiln types: tunnel, rotary, electric arc, resistance, etc.

- » Score 5: Diverse product portfolio; can supply a full range of kiln types for a single plant, facilitating standardization and synchronized operation.
- » Score 3: Strong only in specific kiln types; other types require third-party collaboration.
- » Score 1: Only supplies a very narrow product line.

(c) Level of modernity, high efficiency, environmental friendliness

- » Score 5: There are specific Service Level Agreements (SLAs) and response time commitments (e.g., 24-48 hours); online support and remote monitoring services are provided
- » Score 3: Medium-level technology; acceptable but not optimized efficiency; some upgrades needed to meet standards.
- » Score 1: Outdated technology, low efficiency; difficult to meet environmental requirements without significant additional investment.

2. Experience and technical capability

(a) Years in operation, size of specialized engineering team

- » Score 5: Over 10–15 years in operation; large engineering team with senior specialists/international experience.
- » Score 3: 5–10 years in operation; sufficient engineering team for project implementation but limited in-depth expertise.
- » Score 1: New company, small engineering scale, limited practical experience.

(b) Projects Implemented in Vietnam or the region

- » Score 5: Has multiple, stably operating, similar projects in Vietnam/ASEAN; can provide a clear reference project list and measurable results.
- » Score 3: Only a few similar projects or projects mainly in distant regions (outside ASEAN); limited reference information.
- » Score 1: No similar projects, mainly in trial phases or different markets.

(c) Technical documentation, operational manuals, and training

- » Score 5: Comprehensive documentation (in Vietnamese/English) including SOPs, maintenance manuals, simulation software; offers standardized training programs with periodic updates.
- » Score 3: Basic documentation and initial training available but lacks standardization and long-term updates.
- » Score 1: Fragmented documentation; no clear training program.

3. Support service ecosystem

(a) Customization/design-to-order capability

- » Score 5: Has demonstrated design and manufacturing capability for specific requirements (fuel, layout, process); experience with multiple "tailor-made" projects.
- » Score 3: Can make limited adjustments within predefined boundaries; relies mostly on standard configurations.
- » Score 1: Only provides standard solutions with little flexibility.

(b) Warranty, maintenance, spare parts availability

- » Score 5: Clear service contracts; in-house or regional maintenance teams; stock of essential spare parts in Vietnam/ASEAN.
- » Score 3: Service commitment exists, but parts must be imported with average lead times (e.g., 2–4 weeks).
- » Score 1: No clear service system; parts require special orders with long lead times.

(c) Response time and troubleshooting capability

- » Score 5: Specific SLA/response time commitments (e.g., 24–48 hours); provides online support and remote monitoring.
- » Score 3: Typically provides case-by-case support; no clear SLA.
- » Score 1: Slow response, entirely dependent on schedules of foreign experts.

4. Investment and operating costs

(a) Equipment cost relative to performance

- » Score 5: Initial investment costs are high but with clearly proven efficiency and a short payback period; lifecycle cost analysis (Total Cost of Ownership – TCO) is provided.
- » Score 3: Medium investment cost, acceptable performance level.
- » Score 1: Cost is not commensurate with performance; cannot demonstrate economic benefits.

(b) Long-term operational cost savings

- » Score 5: Measured data or comparative benchmarks are available to demonstrate energy savings, low maintenance costs, and high equipment lifespan.
- » Score 3: Has potential for savings but lacks actual measured data; part of the benefit heavily depends on operational practices.
- » Score 1: Cannot demonstrate operational cost-saving benefits.

(c) Financial support or links to financing (if applicable)

- » Score 5: Offers financing packages, leasing, ESCO models, or links to energy efficiency/green financing programs, banks, or climate funds.
- » Score 3: Provides introductions or assists with loan applications but no dedicated financial packages.
- » Score 1: No financial support offered.

5. Standards compliance

(a) Equipment compliance with ISO, TCVN, IEC, JIS, etc.

- » Score 5: Full certificates/test reports available; key components (burners, control systems, safety devices) are certified to international or equivalent TCVN standards.
- » Score 3: Mostly meets basic standards; some items lack independent certification.
- » Score 1: Lacks clear certificates; standards documentation is not transparent.

(b) Operational safety, emission standards

- » Score 5: Design prioritizes operational safety (interlocks, alarms, emergency stop systems, risk assessment); provides integrated emission control solutions compliant with QCVN/local standards; has a safe operational history.
- » Score 3: Meets minimum legal requirements but lacks advanced safety features or requires additional investment for emission control.

- » Score 1: Poses potential safety risks; cannot demonstrate compliance with environmental regulations.

Enterprises can design a scoring matrix using the criteria groups above, assign appropriate weights, and score each supplier. The resulting ranking serves as a crucial basis for selection. It also provides a transparent rationale for reporting to management, credit institutions, or sponsors regarding the decision for selecting an industrial kiln supplier.

CHAPTER 5. IMPLEMENTATION GUIDELINES AND RELATED REGULATIONS

5.1 Criteria for equipment selection and procurement

During the selection and procurement phase, enterprises should evaluate industrial kiln equipment from a "life-cycle cost" perspective rather than focusing solely on the initial purchase price. The equipment must simultaneously meet requirements for capacity, safety, product quality, energy efficiency, and environmental compliance. Clearly defining criteria from the tender document and procurement contract stage helps mitigate technical risks, avoiding situations where equipment is unsuitable for actual operating conditions, has low performance, or is difficult to integrate with existing systems. The following criteria should be specified as technical requirements, performance guarantee conditions, and contents for commissioning and testing to serve as the basis for evaluating and comparing different suppliers.

Key technical specifications to consider

(1) Capacity and operating load range

Clearly define the rated capacity (tons of steam/hour, kW thermal) and the stable operating load range (minimum – maximum), ensuring it aligns with the plant's actual load profile.

Note: Require the supplier to demonstrate the ability to operate stably and safely at low loads (e.g., 30–40% load) without needing auxiliary fuel firing, to prevent fuel wastage.

(2) Pressure, temperature, and heat transfer medium quality parameters

Specify the required steam or thermal oil pressure and temperature for the process; requirements for steam quality (dry, minimal moisture carryover) or thermal oil temperature stability.

Note: These parameters must be compatible with existing steam/heat piping and utilization equipment to avoid major infrastructure changes.

(3) Fuel type and fuel flexibility

Clearly stipulate the primary fuel type (coal, biomass, oil, gas, etc.), the acceptable fuel characteristic range (moisture content, calorific value, particle size), and any requirements for multi-fuel capability if needed.

Note: Given decarbonization trends, prioritize equipment with the ability to transition to cleaner fuels (biomass, gas, low-carbon liquid fuels) in the future without requiring complete kiln replacement.

(4) Technology configuration and construction materials

Describe the kiln type (fire-tube, water-tube, fluidized bed, static/moving grate, etc.), heat exchange schematic, level of automation; and specify requirements for heat-resistant and corrosion-resistant materials, as well as design lifespan.

Note: Require the supplier to provide schematic diagrams, a list of key materials, and design/manufacturing standards (TCVN, EN, ASME, etc.) to facilitate future inspection, operation, and maintenance.

(5) Auxiliary system requirements

Specify the required characteristics for forced draft fans, induced draft fans, water/oil feed pumps, feedwater treatment systems, flue gas treatment systems, storage tanks, and control-monitoring systems (SCADA, online measurement).

Note: Clearly define minimum efficiency grades for electric motors, fans, and pumps; prioritize using variable frequency drives (VFDs) for speed control to reduce auxiliary power consumption.

(6) Safety and environmental requirements

Specify requirements for safety devices (safety valves, pressure relays, low-water cutoff, flame safeguard, emergency stop interlocks, etc.); requirements for compliance with emission, noise, and ash/slag handling regulations.

Note: Require the supplier to include safety system design documentation, risk analysis, and safe operation manuals to support statutory inspections, labor, and environmental audits.

Performance guarantee criteria

(1) Nominal efficiency and efficiency at actual operating conditions

Require a clear statement of the kiln's nominal thermal efficiency (at 100% load) and its efficiency at typical load levels (e.g., 75% and 50%), including test conditions: fuel type, feedwater quality, ambient temperature.

Note: Require the supplier to provide efficiency vs. load curves and specific fuel consumption (kg fuel/ton of steam or MJ fuel/ton of steam) as a basis for calculating operating costs.

(2) Waste heat recovery and utilization solutions

Consider integrating economizers, air preheaters, flue gas condensers, or heat recovery from blowdown and condensate to improve overall system efficiency.

Note: In their technical proposal, the supplier must specify the flue gas temperature after heat recovery, the expected percentage efficiency gain, and the impact on stack design and corrosion-resistant materials.

(3) Auxiliary equipment efficiency and system losses

Evaluate the efficiency of fans, pumps, and drive systems (direct or belt-driven), as well as losses in piping, insulation, steam leaks, and condensate losses.

Note: Specify minimum standards for insulation and require a commitment on condensate return rate (e.g., ≥ 80 – 90% of steam supplied) to ensure total system efficiency, not just the boiler/kiln body efficiency.

(4) Performance measurement, monitoring, and reporting criteria

The equipment must have sufficient, reliable measurement points and devices (fuel flow, steam flow, temperature – pressure at key points, flue gas O_2 , etc.) for calculating and monitoring efficiency during regular operation.

Note: Integrate data logging and periodic reporting functions to support ISO 50001 energy management, energy saving assessments, and greenhouse gas emission reduction reporting.

(5) Performance guarantee and penalties

The contract must clearly define the guaranteed performance indicators (efficiency %, fuel consumption, maximum flue gas temperature, etc.), the testing methodology, and adjustment conditions.

Note: Design a reward-penalty mechanism: if performance targets are not met, the supplier must correct/upgrade free of charge or accept a price reduction; if targets are exceeded, consider an incentive mechanism.

Commissioning and testing requirements**(1) Commissioning and testing scope and sequence**

Clearly define the steps: review of design documents & certificates, mechanical & electrical installation inspection, no-load testing, step-by-step load testing, and a continuous reliability run for a specified period.

Note: Link each step to specific "acceptance milestones" as a basis for supplier/contractor payment.

(2) Testing content during load testing

Measure and verify efficiency, fuel consumption, steam flow and quality, safety parameters, control system stability, feedwater/condensate quality, emission parameters, and noise levels.

Note: Testing must comply with current standards/regulations; involve an independent consultant or accredited testing laboratory to increase objectivity.

(3) Safety and protection system testing

Test the operation of all protection devices (safety valves, water level cutoffs, pressure cutoffs, fuel shutoff on flame failure, emergency stop interlocks, etc.) under controlled conditions.

Note: Final acceptance is only granted upon proof that the safety system operates as designed; any temporary bypassing of protections during testing must be strictly controlled and fully restored afterward.

(4) Handover documentation and operational training

Require the supplier to provide complete technical documentation, as-built drawings, operation and maintenance manuals, spare parts lists, and organize training sessions for operation and maintenance staff.

Note: Specify minimum training hours, theoretical and practical content, and require the supplier to provide technical support during an extended run-in period (e.g., the first 3–6 months of commercial operation).

(5) Acceptance report and handling of non-compliance

All test results must be compiled in an acceptance report, clearly stating which criteria are met/not met, recommended adjustments, and corrective action plans.

Note: The contract must clearly state the supplier's obligations in case of non-compliance (adjustment, part replacement, re-testing...) and the investor's right to refuse final acceptance until all requirements are met.

The content and criteria above will form the basis for tender document preparation, technical proposal evaluation, and quality management throughout the industrial kiln's lifecycle.

5.2 Technical & safety considerations for technology application

When implementing any new industrial kiln technology, enterprises must consider the management of technical and safety risks as a core design pillar from the pre-feasibility study and technology selection phases through to installation, commissioning, and commercial operation. The more complex the technology and the higher the automation level, the more stringent the requirements for design standards, protection systems, operating procedures, and personnel competency must be. The following content should be translated into requirements for tender documents, procurement contracts, internal procedures, and serve as a basis for inspection throughout the equipment's lifespan.

In addition, an operational, maintenance, and repair checklist for energy-saving technologies should be established and applied to ensure safety and effectiveness when implementing these technologies. A suggested checklist template is provided in the appendix of this Catalog.

5.2.1 Technical and safety risks

(1) Fire, explosion, and overpressure risks

Hazards due to accumulation of unburned fuel, backfire, kiln explosions, steam or tank explosions from overpressure, safety valve failures, or improper operation.

Note: Conduct hazard identification from the design stage; evaluate worst-case scenarios to properly size and locate safety valves, relief vents, blast walls, and safety distances.

(2) Leakage of combustible gas, toxic gas, and fuel

Leaks of fuel gas, flue gases, dust, chemical vapors, or liquid/gaseous fuel pose risks of fire, explosion, poisoning, and harm to worker health and the surrounding environment.

Note: The kiln area must be designed with adequate ventilation, gas leak detectors, and alarms; all piping and fittings must comply with pressure standards and be subject to regular leak testing.

(3) Structural failure and equipment degradation

Deformation, cracking of kiln walls, fire/water tubes, grates, or support steel structures due to high temperatures, corrosion, abrasion, load fluctuations, or uneven foundation settlement.

Note: Require the supplier to provide strength calculations and material certificates; the investor must organize periodic inspections, ultrasonic testing, or radiography (if needed) for critical areas.

(4) Risks from electrical and control systems

Power failure, electrical panel fires, controller malfunctions, or sensor errors leading to incorrect operation, loss of protective functions, sudden shutdowns, or operation outside safe limits.

Note: The design must include layered protection, backup power (UPS, generators), clear safety interlocks; control software must have access control levels and log all interventions.

(5) Risks to operators and the work environment

Risks of burns, crushing, falls from height, noise, vibration; exposure to dust and hot gases; confined spaces, unsafe walkways, and access routes.

Note: Incorporate ergonomics into the design: convenient access for operation/maintenance, installation of railings, stairs, and work platforms, proper lighting and ventilation, and mandatory use of full personal protective equipment (PPE).

5.2.2 Safety requirements for technology application

(1) Compliance with standards, regulations, and legal requirements

The design, manufacture, installation, inspection, and operation of industrial kiln and furnace system must comply with national technical regulations for boilers,

pressure vessels, occupational safety, fire prevention and fighting, and environmental protection.

Note: Enterprises must maintain an updated list of applicable standards and regulations; the contract must clearly define the supplier's responsibility for legal documentation, certifications, and initial inspection.

(2) Technical-technological safety systems

Fully equip the system with safety valves, pressure relays, water level protection, flame monitoring devices, automatic fuel shut-off valves, mechanical-electrical-control interlocks, and local fire alarm and suppression equipment.

Note: Bypassing safety protections for operational convenience is strictly prohibited; any changes must undergo risk assessment and receive written approval.

(3) Safe operating procedures and specific work instructions

Develop and issue standardized operating procedures for each kiln technology, covering start-up, load increase, shutdown, handling of abnormal situations, fuel switching procedures, etc.

Note: Procedures should be standardized as concise, easy-to-understand "work instructions" posted on-site; they must be reviewed and updated periodically based on operational experience.

(4) Operator competency and safety training

Require operators and maintenance personnel to receive appropriate training and certification; provide periodic safety, fire-fighting, emergency response training, and refresher courses when technology changes.

Note: Link training requirements to procurement terms, requiring the supplier to conduct initial training and provide technical support during the early operation phase.

5.2.3 Periodic maintenance and life-cycle equipment management

(1) Planned maintenance program

Develop a plan for routine maintenance (per shift, daily, weekly), periodic maintenance (monthly, quarterly, annually), and major overhauls based on operating hours.

Note: Apply preventive maintenance or condition-based maintenance methodologies using measurement indicators, rather than relying solely on breakdown repairs.

(2) Periodic safety inspection and assessment

Organize technical safety inspections as required by regulations (for boilers, pressure vessels, liquefied gas systems, etc.); check for leaks, structural integrity, and safety devices; assess compliance with standards after major repairs.

Note: Inspection records and test reports must be properly archived and retrievable; all recommendations from the inspection body must be addressed before restarting the equipment.

(3) Spare parts, materials, and operation/maintenance log management

Establish a list of critical spares and materials; manage minimum inventory levels; maintain operation and maintenance logs to track failure trends and performance.

Note: This data forms the basis for optimizing maintenance plans, reducing downtime, and serves as evidence when assessing responsibilities between the investor and supplier.

5.2.3 Emergency response and incident management

(1) Emergency response plan and fire prevention/fighting plan

Develop incident scenarios (kiln fire, explosion, gas leak, widespread power outage, fuel spill, etc.), clearly describing the action sequence: detection – alarm – isolation – suppression – evacuation – recovery.

Note: The plan must be approved by competent authorities as per fire prevention regulations and regularly drilled to ensure feasibility.

(2) On-site information and command system

Clearly define the on-site commander, safety officer, communication channels, and alarm methods; install clear, visible escape route maps, safety signs, and instructions.

Note: Ensure all workers on every shift know the locations of fire-fighting equipment, emergency fuel shut-off valves, and escape routes.

(3) Post-incident review and continuous improvement

After any incident or "near miss," conduct a root cause investigation, draw lessons, update procedures, and implement necessary technical or organizational improvements.

Note: Recording and analyzing near misses is an effective tool for preventing serious accidents and enhancing the plant's safety culture.

The technical and safety considerations above must be integrated coherently into the design, technology selection, procurement contracts, and operational management system to minimize risks, protect workers, and ensure the stable, efficient long-term operation of industrial kiln and furnace system.

5.3 M&V procedure for energy efficiency

M&V of energy savings is a mandatory step to prove that industrial kiln improvement solutions deliver real benefits in energy, cost, and greenhouse gas emission reduction. The procedure must be standardized and consistently applied before, during, and after project implementation to ensure reliable results that can be used as a basis for further investment decisions and reporting to stakeholders (management, regulatory bodies, financial institutions, etc.).

M&V objectives and scope

Objectives:

- Determine the achieved energy and fuel cost savings after implementing the solution.
- Calculate the reduction in CO₂ emissions compared to the pre-investment state.
- Assess the level of compliance with the performance targets committed in the contract/project plan.

Scope:

- Clearly define the equipment, process, or production line under consideration (kiln, fuel supply system, steam/hot gas system, auxiliaries, etc.).
- Define the system boundary: only the kiln itself, or including the steam distribution system, heat recovery, flue gas treatment, etc.

Note: These elements must be clearly described in the "M&V Plan" developed before project implementation to avoid changes during execution unless formally approved.

M&V Procedure

Step 1 – Establishing the baseline

- » Collect operational data from the kiln for the period before the retrofit (minimum 6–12 months if available):
 - Product output (tons/month, tons/day).
 - Fuel consumption (kg, Nm³, liters...) and fuel characteristics.
 - Key operating parameters: temperatures, pressures, kiln efficiency (if available), downtime...
- » Analyze the influence of factors like production output, product quality, environmental conditions, and operating hours to determine a suitable baseline model.

Step 2 – Planning post-retrofit measurement

- » Define the parameters to be measured (list of measurement points, sensor types, ranges, accuracy levels).
- » Specify the measurement frequency (per shift, daily, continuous via data logging...).
- » Define responsibilities for measurement, recording, data storage, and cross-checking.

Step 3 – Data collection in the post-retrofit period

- » Measure the defined parameters for a sufficiently long period, ensuring production conditions are comparable to the pre-retrofit period.
- » Verify data quality, excluding days with abnormal operation (breakdowns, special tests...).

Step 4 – Normalizing conditions and calculating savings

- » Adjust (normalize) post-retrofit data to match baseline conditions (output, product quality, ambient temperature...) to exclude factors outside the project's scope.
- » Calculate energy, fuel, and cost savings using the formulas agreed upon in the M&V Plan.

Step 5 – Verification and approval of results

- » Compare calculated results with the predefined targets.
- » Conduct independent verification (if needed) by internal audit, a consultant, or a certification body.
- » Prepare an M&V Report, obtain management approval, and archive the report along with the raw data.

Note: Enterprises can adjust the steps for measurement and verification to align with the energy-saving technology solutions that are implemented. Enterprises can refer to internationally recognized M&V methods (e.g., Options A, B, C, D in international M&V guidelines) to design an M&V Plan suitable for the project's scale and complexity.

Below is an example of measuring and verifying the energy savings of an energy-saving solution for industrial kiln and furnace system, for businesses to reference.

Illustrative example: measurement and verification (M&V) of savings for an excess oxygen optimization solution (reducing excess air) in a gas-fired kiln

Step 1. Define M&V scope and objectives

- » **Solution:** Adjusting the combustion regime to bring excess oxygen to the target range (e.g., 2–4% for gas; the specific range is established by the facility based on technology and safety requirements).
- » **Objective:** Reduce specific fuel consumption (Nm³ of gas per unit of product) and/or reduce fuel consumption at the same level of output and quality.
- » **Assessment Boundary:** Covers the entire kiln (from the fuel supply point to the stack), including related fans (forced draft/induced draft).

Step 2. Select Indicators and Assessment Method

- » **Primary Indicator (Priority):**

Specific Fuel Consumption: $SEC = \text{Fuel Consumption} / \text{Standard-compliant Output}$

- » **Supporting Indicators:**

Excess oxygen at stack (% O₂), flue gas temperature (°C), product quality/compliance rate, stable operating time.

- » **Comparison Principle:** Compare conditions before and after the improvement under equivalent operating conditions.

Step 3. Establish the Baseline (Pre-improvement)

- » **Baseline Period:** Minimum 1–2 weeks or ≥ 10–20 stable operating shifts.

- » **Baseline Conditions:**

- Select a period with:
- the same product type/quality standard,
- a similar load range,
- the same fuel type.

- » **Data to Collect (recommended frequency):**

- Fuel consumption (gas meter/flow measurement): per shift or per hour.
- Output: per shift.
- %O₂ and flue gas temperature: hourly (or minimum twice per shift).

- » **Baseline Result:** Calculate SEC_{baseline} (average) and its fluctuation range.

Step 4. Develop the Measurement Plan (equipment, measurement points, frequency, data quality control)

- » **Mandatory measurement points:**

- **Fuel:** Total fuel flow / fuel meter into the kiln
- **Output:** Standard-compliant output per shift
- **Excess oxygen:** O₂ probe at a stable measurement point on the flue duct

» **Recommended measurement points:** Flue gas temperature, fan speed/operating level, kiln chamber pressure (if available).

» **Data quality control:**

- Schedule calibration of O₂ sensor,
- Reconcile total fuel consumption daily/weekly,
- Define how to identify and exclude "abnormal shifts" (kiln stoppage, product defects, product changes).

Establish measurement and verification forms using the sample templates provided below.

Form MV-01: Per-shift Data Collection Sheet (Excess Oxygen Optimization)

Project/Solution Info: Excess Oxygen Optimization – Reducing Excess Air for Kiln _____

Plant: _____ | **Kiln ID:** _____ | **Product:** _____ | **Fuel:** _____

Phase: [] Pre-improvement (Baseline) [] Post-improvement

Date: //____ | **Shift:** _____ | **Recorded by:** _____ | **Verified by:** _____

A. Operating Conditions

Shift start time: _____ Shift end time: _____ Total stable operating hours in shift: _____ hours

Operating load (if any): _____ % / Capacity _____

Notes on abnormal changes during the shift (if any): _____

Is this shift included in calculations? [] Yes [] No

→ Reason for exclusion: _____

B. Output and Quality

Total output: _____ (unit)

Standard-compliant output (Grade A/meeting quality): _____ (unit)

Compliance rate: _____ %

Quality notes (if any): _____

C. Fuel

Fuel meter/flow reading start of shift: _____

Fuel meter/flow reading end of shift: _____

Fuel consumed during shift (calculated): _____ (Nm³ gas / liter / kg)

D. Excess Oxygen and Flue Gas Temperature (record per measurement time)

Time of Measurement	Excess O ₂ (%O ₂)	Flue Gas Temp (°C)	Notes
Start of shift			
Middle of shift			
End of shift			

E. Quick Checklist (to ensure data reliability)

- O₂ sensor functioning normally, no error alerts
- Kiln doors properly sealed, no prolonged abnormal openings
- No major kiln stoppages/incidents during measurement period
- No product type change during the shift (or clearly noted for conversion)

Step 5. Implement the Solution and Conduct Technical Acceptance

» Adjust the combustion regime following safety procedures:

- Check for leaks, interlocks, flame stability,
- Gradually adjust to bring O₂ to the target range,
- Record all setting changes (setpoints, air-fuel ratio limits, fan mode, etc.).

» **Acceptance Criteria:** Kiln operates stably, product quality does not decrease, O₂ remains within the target range during stable operation.

Step 6. Post-improvement Measurement and Normalization of Comparison Conditions

- **Post-improvement measurement period:** Minimum equivalent to baseline (1–2 weeks or ≥ 10–20 shifts).
- **Principles for ensuring equivalence:**
 - Same product type or converted to "standard-compliant output",
 - Exclude abnormal shifts as defined in Step 4,
 - Clearly note any changes unrelated to the solution (major maintenance, fuel change, feedstock change, etc.).

Step 7. Calculate Savings and Verify Results

- **Calculate post-improvement SEC:**

SEC_{after} = Fuel (after) / Standard-compliant Output (after)

- **Relative Savings (%):**

Energy Saving Rate = (SEC_{baseline} – SEC_{after}) / SEC_{baseline} × 100%

- **Absolute Savings (fuel):**

Fuel Saved = (SEC_baseline – SEC_after) × Output (after)

- **Illustrative Example Data (assumed):**

- SEC_baseline = 12.0 Nm³/product unit
- SEC_after = 10.8 Nm³/product unit
- Energy Saving Rate = (12.0 – 10.8)/12.0 = 10%
- If monthly output = 50,000 product units → Fuel Saved = 1.2 × 50,000 = 60,000 Nm³/month

- **Cross-Verification (recommended):** Check the trend of O₂ decreasing into the target range and flue gas temperature decreasing/stabilizing (if data available), while confirming no decline in product quality.

Form MV-02: Calculation summary (before-after comparison, savings calculation)

General Info: Plant ____ | Kiln ID ____ | Aggregation Period: from ____ to ____

Output Unit: ____ | **Fuel Unit:** ____

A. Data Summary by Phase

Indicator	Pre-improvement (Baseline)	Post-improvement	Notes
Number of valid shifts (not excluded)			
Total standard-compliant output (Q)			
Total fuel consumed (F)			
Average excess oxygen (%O ₂)			
Average flue gas temp (°C)			

B. Calculate Specific Consumption and Savings

Pre-improvement SEC (SEC_baseline) = F_before / Q_before

= _____ (fuel unit / product unit)

Post-improvement SEC (SEC_after) = $F_{\text{after}} / Q_{\text{after}}$
 = _____ (fuel unit / product unit)

Savings Rate (%) = $(SEC_{\text{baseline}} - SEC_{\text{after}}) / SEC_{\text{baseline}} \times 100\%$
 = _____ %

Absolute Savings (Fuel_saved) = $(SEC_{\text{baseline}} - SEC_{\text{after}}) \times Q_{\text{after}}$
 = _____ (fuel unit)

C. Sanity Check (must be filled)

Has product quality changed adversely?

No Yes (describe) _____

Were there major changes unrelated to the solution (fuel, feedstock, major repairs, shift/crew changes)?

No Yes (describe) _____

Verification Conclusion: Pass Fail | Reason/Recommendation:

Prepared by: _____ Date: ____

Checked/Verified by: _____ Date: ____

Step 8. M&V reporting and sustaining results

The report should include at minimum:

- Description of the solution and scope,
- Baseline and post-improvement data (data sources, time periods, excluded shifts),
- Savings results (absolute and relative),
- Impact on quality/output,
- Recommendations for sustaining results: target O₂ range, sensor calibration schedule, per-shift checklist, and alarm thresholds.

KPIs for assessing energy saving effectiveness

(1) Specific Energy Consumption (SEC) (Primary KPI)

Definition: The amount of thermal energy or fuel consumed to produce one unit of product.

Reference formula:

» Specific energy consumption (SEC):

$$SEC = \frac{Q_{fuel} \times \text{Calorific Value}}{\text{Production value}} \left(\frac{MJ}{\text{Production output}} \right)$$

Where:

- Q_{fuel}: Total fuel consumption during the calculation period (unit: tons, liters, etc.)
 - Heating Value: Calorific value of the fuel (kJ/unit)
 - Production Output: Output during the calculation period (tons of product)
- » Or, Unit Fuel Consumption: kg of fuel/ton of product; Nm³ of gas/ton of product.

Objective: Reduce the SEC or unit fuel consumption compared to the baseline.

(2) Achieved CO₂ emission reduction

Definition: The equivalent amount of CO₂ emissions avoided due to fuel savings.

Reference formula:

$$\Delta CO_2 = \Delta Q_{fuel} \times \text{Emission factor} \left(\frac{tCO_2}{\text{year}} \right)$$

Where:

- ΔCO₂: Amount of CO₂ emissions reduced in the calculation year (tCO₂/year)
- ΔQ_{fuel}: Total quantity of fuel reduced in the calculation year (tons, liters, etc.)
- Emission factor: CO₂ emissions per unit of fuel.

Applications:

- Reporting to state management agencies on greenhouse gas emission reductions.
- Assessing eligibility for participation in carbon finance mechanisms, green certificates, or greenhouse gas credit programs (if applicable).

(3) Annual fuel cost savings

Definition: The monetary value of the fuel saved during one year of operation.

Reference Formula:

$$\text{Annual Cost Savings} = \Delta Q_{fuel} \times \text{Unit Fuel Price} \left(\frac{VND}{\text{year}} \right)$$

Supplementary indicators:

- Simple Payback Period: Total Investment Cost / Annual Cost Savings.
- Internal Rate of Return (IRR): For detailed financial analysis.

(4) Recommended supplementary indicators

- Kiln efficiency (based on thermal balance), condensate return rate, percentage of operating time within the optimal load range.
- Specific auxiliary electricity consumption (kWh/ton of product) for fans, pumps, control systems, etc.

Note: The final results report should clearly present the value of each indicator before and after implementing the solution, the absolute and relative (%) improvement, and clearly state the assumptions and data sources used for the calculations.

Implementation organization and reporting

Designate a primary person/department responsible for M&V (typically the Energy Management unit or Technical Department).

- Clearly define the roles and responsibilities of the kiln operations team, accounting/statistics department, and environmental department in providing and verifying data.
- Establish a reporting frequency (e.g., monthly summary reports, comprehensive annual review reports) and integrate them into the company's overall energy and environmental reporting.

The Measurement and Verification procedure outlined above, combined with a clear set of KPIs, enables enterprises to transparently demonstrate the energy-saving effectiveness of their industrial kiln solutions. This supports investment decision-making, facilitates financial mobilization, and strengthens internal energy management capabilities.

5.4 Assessment support tools

Relying solely on the experience of technical staff is insufficient when selecting technology, appraising projects, and monitoring the operational efficiency of industrial kiln and furnace system. Enterprises need to utilize systematic assessment support tools, including calculation and simulation software, as well as standardized evaluation forms. These tools help quantify technical, energy, and environmental indicators, compare investment options, and record qualitative assessments such as safety levels, flexibility, and operability/maintainability. The integrated application of these support tools enhances decision-making quality, ensures transparency, and improves the traceability of the entire evaluation process.

Thermal-energy simulation software

(1) Purpose of use

- » To support the calculation of heat and mass balances for the kiln and auxiliary systems, thereby estimating efficiency, fuel consumption, and heat losses.
- » To analyze and compare improvement scenarios (e.g., changing heat exchanger configurations, adding economizers, recovering waste heat, switching fuel types).
- » To forecast the impact of different operating conditions (kiln load, fuel quality, environmental conditions) on efficiency and operational costs.

(2) Software types and levels of detail

- » **Simplified calculation software** (spreadsheets, quick calculators): Used for preliminary screening to quickly estimate specific consumption and payback periods.
- » **Detailed simulation software** (2D/3D models, CFD...): Allows for the examination of temperature distribution, gas flow, and combustion within the kiln, suitable for optimal design phases or major retrofits. Enterprises can select the appropriate level based on project scale, personnel capability, and available time.

Below are some representative software tools recommended for use in surveying, simulating, and assessing the energy efficiency of industrial kiln and furnace system and steam/heat systems:

MEASUR – Manufacturing energy assessment software for utility reduction (U.S. DOE)

- » **Function:** A free software suite from the U.S. Department of Energy with over 70 calculation tools for various industrial systems (steam, heating, pumps, fans, compressed air, etc.).
- » **Relevance to Industrial kiln and furnace system:** Includes modules for assessing heating systems and boilers/steam systems, allowing calculation of efficiency, heat balance, and potential energy, cost, and CO₂ savings.
- » **Website:** <https://www.energy.gov/eere/iedo/measur> and web version: <https://measur.ornl.gov/>

PHAST – Process heating assessment and survey tool (U.S. DOE)

- » **Function:** A specialized tool for heating/combustion process systems (kilns, kilns, dryers, heat treatment ovens...). It allows for the assessment of fuel, steam, or electric heating equipment, calculating heat balance and identifying losses and savings potential.

- » **Application:** Suitable for detailed evaluation of industrial kiln and furnace system/dryers, forming the basis for proposing waste heat recovery, insulation improvement, and excess air optimization solutions.
- » **Website:** <https://www.energy.gov/eere/iedo/articles/process-heating-assessment-and-survey-tool>

RETScreen Expert – clean energy management software (Government of Canada)

- » **Function:** A clean energy project management and analysis software platform. It enables the technical-financial assessment of energy efficiency, cogeneration, and renewable energy projects, while also supporting Measurement and Verification (M&V) and portfolio management.
- » **Relevance to Industrial kiln and furnace system:** Results from energy analysis tools (such as MEASUR/PHAST) can be imported to assess financial effectiveness, including payback period, internal rate of return (IRR), net present value (NPV), while also estimating the CO₂ emission reduction of the kiln retrofit project.
- » **Website:** <https://www.nrcan.gc.ca/maps-tools-publications/tools/retscreen/7465>

eQUEST – DOE-2.2 based building & system energy simulation

- » **Function:** A free energy simulation software based on the DOE-2.2 engine, primarily for buildings. However, it can model heat sources (boilers, heaters), steam/thermal loads, and distribution systems to assess the impact of kiln retrofits on the entire plant.
- » **Application:** Used for system-level studies when evaluating the role of the kiln within the plant's overall energy balance.
- » **Website:** <http://www.doe2.com/equest/>

Aspen Plus / Aspen HYSYS (AspenTech)

- » **Function:** An advanced process simulation software suite. It enables detailed modeling of reactions, heat exchange, distillation, kilns, reformers, heat exchanger networks, etc., in industries like chemicals, petrochemicals, and materials.
- » **Application:** Suitable for complex industrial kiln projects deeply integrated into process lines (e.g., kilns in chemical plants, refineries), requiring optimization of the entire heat and material balance.
- » **Website:** <https://www.aspentech.com/en/products/engineering/aspen-plus>

CFD Simulation software for combustion chambers: Ansys Fluent, COMSOL Multiphysics, OpenFOAM

- » **Function:** Detailed simulation of fluid dynamics and heat transfer within combustion chambers, flues, and heat exchange zones; analyzing temperature distribution, O₂ concentration, NO_x, CO, gas velocity, etc.
- » **Application:** Used in the design of new or major retrofit industrial kiln and furnace system to optimize burner placement, kiln geometry, reduce hot spots, and improve efficiency while reducing emissions. Typically used by consultants or technology suppliers.
- » **Main websites:**
 - **Ansys Fluent:** <https://www.ansys.com/products/fluids/ansys-fluent>
 - **COMSOL Multiphysics:** <https://www.comsol.com/>
 - **OpenFOAM:** <https://openfoam.org/>

(3) Requirements for implementation

- » Input data sets must be reviewed and standardized (fuel characteristics, kiln parameters, actual operating conditions) to avoid errors caused by inappropriate assumptions.
- » An internal procedure for software use should be established, including a common version, designated personnel responsible for modeling, and steps for cross-checking simulation results against actual measured data.
- » It is recommended to fully archive models and input/output data to facilitate updates and adjustments in subsequent evaluations.

Note: The use of simulation software does not entirely replace on-site measurements but serves as a supplement to optimize solutions and reduce risks during the design and investment phases.

Quantitative and qualitative assessment forms

(1) Quantitative assessment forms

These record measurable indicators, for example:

- » Specific fuel consumption, specific energy consumption per unit of product.
- » Quantity of heat recovered, kiln efficiency, specific CO₂ emissions.
- » Fuel costs, operation and maintenance costs, investment payback period. Each form must clearly specify the data source, unit of measurement, calculation method, and the measurement period (before/after solution implementation) to ensure comparability.

(2) Qualitative assessment forms

These record factors that are difficult to quantify but have significant influence on investment decisions and operations, including:

- » Safety level, technical risks, reliability, and operational stability.
- » Operator-friendliness (ease of operation, ease of maintenance, required personnel skill level).
- » Flexibility in changing fuel type, adjusting capacity, and integration with existing systems.
- » Impact on corporate image, and ability to meet customer and regulatory requirements.

Qualitative criteria should be scored using a standard scale (e.g., 1–5 points or 1–10 points) accompanied by specific scoring guidelines to reduce subjectivity.

(3) Standardization and integration of forms

- » It is recommended to use a unified set of forms across the entire enterprise/project chain, avoiding the use of different formats by different departments which hinders consolidation and comparison.
- » These forms should be integrated into the Energy Management System (EnMS), Asset Management System, or ERP software, facilitating data updates and automated report generation.
- » Forms should be reviewed and updated periodically to align with new regulations, standards, and lessons learned from implemented projects.

Effectively combining thermal-energy simulation software with a system of quantitative and qualitative assessment forms provides enterprises with a comprehensive toolkit for objectively, transparently, and consistently evaluating, comparing, and making investment decisions regarding industrial kiln solutions.

5.5 Applicable legal regulations and standards

Activities related to the investment, installation, and operation of industrial kiln and furnace system must comply simultaneously with the legal frameworks concerning energy efficiency and conservation, occupational safety and pressure equipment, and environmental protection. In addition to the domestic system of laws, decrees, and circulars, enterprises are recommended to reference international (ISO) and Vietnamese national standards (TCVN) to standardize design, operation, and energy management. The following regulations and standards are the primary references related to thermal equipment efficiency, industrial emissions, and combustion equipment safety.

Regulations on thermal equipment efficiency and energy management

The Law on Economical and Efficient Use of Energy and its guiding documents:

- » Stipulate the responsibilities of designated large energy-consuming facilities in developing energy plans, reporting energy use, conducting energy audits, and implementing energy efficiency solutions for kilns and steam/thermal systems.
- » Serve as the legal basis for requiring enterprises to set energy efficiency targets and indicators for thermal equipment and monitor their achievement.

ISO 50001 – Energy Management Systems (EnMS):

- » Specifies requirements for establishing, implementing, maintaining, and improving an Energy Management System (EnMS), applicable to all types of organizations.
- » This standard supports enterprises in establishing an energy policy, setting objectives, developing Energy Performance Indicators (EnPIs) for industrial kiln and furnace system, implementing measurement and control, conducting internal audits, and pursuing continual improvement.
- » Recommendation: For facilities with multiple industrial kiln and furnace system, implementing ISO 50001 is advisable to integrate kiln performance requirements into the company's overall management system.

Regulations on Industrial Emissions and the Environment

QCVN 19:2024/BTNMT – National technical regulation on industrial emissions:

- » Stipulates the maximum allowable limits for pollutants (dust, SO₂, NO_x, CO, volatile organic compounds, H₂S, etc.) in industrial emissions released into the environment.
- » Serves as the basis for designing kiln flue gas treatment systems (dust filters, SO₂/NO_x removal, VOC treatment, etc.), selecting combustion technology, and is the standard for regulatory inspections, monitoring, and violation handling.

Other sector-specific regulations:

- » QCVNs for waste incinerators, municipal solid waste incinerators, and sector-specific emission regulations establish specific requirements for different types of incinerators and waste streams.
- » Some earlier documents such as QCVNs for boiler emissions and industrial kiln emissions may still be referenced or cited in technical documentation

and contracts; enterprises should refer to the latest versions issued by the Ministry of Natural Resources and Environment (MONRE).

Note: When preparing investment or retrofit projects for kilns, the investor must clearly identify the emission source type to apply the correct corresponding emission regulations, and calculate treatment solutions ensuring a margin of safety relative to the stipulated limits.

Industrial kiln and furnace system safety standards

TCVN 2294:1978 – Heat treatment of metals – General safety requirements:

- » Applicable when kilns are used for heat treatment; serves as the basis for developing safe operating procedures, personal protective equipment requirements, workplace organization, and hazard control.

TCVN 3196:1979 – Industrial resistance kilns for heating and heat treatment – Terms and definitions:

- » Used to standardize terminology in technical documentation, drawings, training materials, and acceptance procedures for resistance kilns.

TCVN 3202:1979 – Electric and induction kilns and equipment – Terms and definitions:

- » Used to standardize terminology for electric and induction kilns and equipment, supporting unified technical requirements and training.

QCVN 25:2025/BCT – National technical regulation on electrical safety:

- » Mandatorily applicable to electrical components of kilns (electrical cabinets, grounding, protection, safe operation, power isolation, periodic inspections, etc.).

TCVN 3254:1989 – Fire safety – General requirements:

- » Applicable to fire prevention and risk mitigation in kiln areas; includes management of heat sources, combustible materials, firefighting equipment, and emergency response training.

QCVN 06:2022/BXD – Fire safety for buildings and structures:

- » Applicable to the layout of kiln areas within workshops/buildings (fire compartments, escape routes, safe distances, etc.).

TCVN 7383-1:2004 (ISO 12100-1) – Safety of machinery – Basic concepts, general principles for design (reference standard):

- » Applied for hazard identification, risk assessment, and selection of mitigation measures (guarding, interlocks, emergency stops, etc.), particularly useful during kiln retrofitting or control system modifications.

Safety inspection regulations

- » Circulars and inspection procedures (e.g., Circular 54/2016/TT-BLĐT BXH) stipulate the periodicity, scope, content, and methods for technical safety inspection of boilers and pressure equipment: applicable to pressure equipment within industrial furnace systems.
- » Enterprises must ensure that pressure equipment is inspected on schedule, with complete records and documentation, and that any recommendations from the inspection organization are addressed before the equipment is put into operation.

International standards on combustion equipment and gas treatment

ISO 13577 – Industrial kiln and furnace system and associated processing equipment – Safety:

This set of standards specifies general safety requirements for industrial kiln and furnace system and heating equipment. It includes:

- » Part 1: General safety requirements for industrial kiln and furnace system and associated heating equipment.
- » Part 2: Safety requirements for combustion and fuel handling systems.
- » Part 3: Addresses safety concerning:
 - Storage, mixing stations, pipelines – valves – safety equipment; hazardous area classification and ventilation;
 - Measurement – monitoring of O₂, H₂, CO, dew point/humidity, pressure – flow rate;
 - Purging – inerting procedures, prevention of explosive mixture formation and fire spread;
 - Emergency stop interlock, leak alarms, safe venting/flaring systems; specific requirements for vacuum kilns, protective atmosphere heat treatment kilns, and procedures for introducing/removing atmospheres to/from the kiln chamber.
- » Part 4: specifies requirements for the protective systems of industrial kiln and furnace system.
 - Although its scope primarily applies to firing and heating kilns and equipment, and does not directly apply to boilers, the principles concerning safety design, protective systems, and sensor-interlock equipment in ISO 13577 can still be referenced when designing or retrofitting industrial kiln and furnace system in Vietnam.

Other relevant standards and regulations on flue gas treatment and combustion systems

QCVNs, TCVNs on flue gas treatment systems, waste incinerators, dust filtration equipment, SO₂/NO_x treatment, as well as international standards (EN, ISO) on the performance of filtration equipment, absorption devices, etc., serve as the basis for selecting and commissioning gas treatment equipment for kilns.

Implementation guidance for enterprises

When preparing a new kiln investment or retrofit project, compile a summary table of applicable regulations and standards (laws, decrees, QCVNs, TCVNs, ISO) and clearly assign responsibility for compliance with each group of requirements (energy, environment, safety) to specific units.

In tender documents, procurement contracts, technical designs, and operating procedures, explicitly cite the aforementioned standards and regulations, treating them as the minimum conditions for suppliers and contractors in designing, manufacturing, installing, and handing over the equipment.

Periodically review and update practices when new versions of QCVNs/TCVNs or ISO standards are issued, ensuring that the industrial kiln system always complies with current legal requirements and best practices in energy management, safety, and environment.

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APPENDIXES

1 Technology Readiness Level (TRL) Scale

TRL	Description of technology readiness level	Minimum evidence/output (suggested)
1	Observation and description of basic principles	Scientific literature, description of mechanism/phenomenon
2	Formation of technology concept/application idea	Concept description, schematic diagram, technical hypothesis
3	Proof of concept at initial experimental level	Small-scale testing, measurement results confirming the principle
4	Validation in laboratory environment (prototype/test equipment)	Prototype operates under controlled conditions; test report
5	Validation in near-realistic environment (semi-industrial)	Test equipment/module under realistic load/noise; stable data
6	Demonstration at pilot scale in relevant operational environment	Pilot model/site with similar conditions; operational–safety assessment
7	Demonstration at near-commercial scale in actual operating conditions	Installation at plant site, trial/stable shift operation; preliminary performance parameters
8	System completion and validation; ready for commercial deployment	Complete design documentation, trial run acceptance, operation–maintenance procedures
9	Full commercialization, with multiple stable operational projects	Multiple long-term operational projects; proven effectiveness/reliability

2. Checklist for safety and efficiency in the operation, maintenance, and repair of energy-saving equipment and technologies in industrial kiln and furnace system

Enterprises can refer to the following 6 checklists to develop appropriate inspection forms:

1. CL-01: Pre-start Checklist
2. CL-02: Start-up & Warm-up Checklist
3. CL-03: Normal Operation Checklist (per shift)
4. CL-04: Shutdown & Cool-down Checklist

5. CL-05: Abnormal & Emergency Situation Checklist
 6. CL-06: Periodic Maintenance Checklist for Industrial kiln and furnace system (for reference)
-

CL-01. Pre-start checklist

General Info: Date/Time ____ | Shift ____ | Area ____ | Kiln ID ____ | Performed by ____
Approved by ____

A. Area Safety

- » Area around kiln is clean, free of flammables/obstructions.
- » Warning signs, barriers, and escape routes are clear.
- » Firefighting equipment is ready (sealed, pressurized, in place).
- » Complete PPE available (gloves, goggles, mask, shoes, heat-resistant clothing).

B. Mechanical Condition – Kiln Structure

- » Kiln doors/locks function well, seal properly; gaskets in good condition.
- » Inspect refractory lining: no major spalling or dangerous cracks.
- » No abnormal leaks at air ducts/stacks/related piping.

C. Fuel – Air – Electrical

- » Sufficient fuel for operation shift; quality meets requirements (moisture/impurities).
- » Fuel lines: no leaks, shut-off valves functional, filters clean.
- » Combustion air/fume fans test run correctly, proper rotation direction, no abnormal vibration.
- » Electrical system: control panels, circuit breakers, grounding, emergency stops are ready.

D. Instrumentation & Control

- » Temperature sensors display normally; readings plausible for current state.
- » Pressure/flow gauges (if any) display normally.
- » (If applicable) Excess O₂/gas analyzers display normally.
- » Safety interlocks are ready (flame failure, overtemperature, abnormal pressure...).

Conclusion: [] Conditions met for start-up [] Conditions not met (specify)

CL-02. Start-up & warm-up checklist

- » Follow correct start-up sequence per SOP.
 - » Check ignition/flame stability (if burner): stable flame, no pulsation/flashback.
 - » Heat ramp-up per schedule: rate ____ °C/h (as required).
-

- » Record zone temperatures (if any): Z1 ___ Z2 ___ Z3 ___
- » Monitor excess oxygen (if any): ___ %; adjust to avoid excess air.
- » No abnormal noises/vibrations from fans, valves, or piping.
- » Exhaust fumes/smoke: normal color, no unusual odor.

CL-03. Normal Operation Checklist (per shift)

Suggestion: Perform at least twice per shift (beginning and middle).

A. Key Operating Parameters

- » Setpoint/measured temperature meets requirement: ___ °C (by zone if applicable).
- » Fuel: flow/pressure stable, no large fluctuations.
- » Combustion air & induced draft: stable; no significant air in-leakage.
- » (If applicable) Excess O₂ maintained within target range: ___ % (range –%).

B. Losses – Quick Check of Energy-Saving Points

- » Kiln doors remain closed; unnecessary openings minimized.
- » Kiln shell surface: no abnormal "hot spots" (mark location if found).
- » No leaks at doors/gaps/hot piping.
- » Heat recovery equipment (if any): stable inlet/outlet temperature differential, no blockage.
- » Dust filters/flue gas treatment (if any): differential pressure within limits, not overloaded.

C. Safety & Operational Discipline

- » No interlock alarms; if any, record and address.
- » Operation log updated: fuel consumption, production, abnormal events.

CL-04. Shutdown & cool-down checklist

- » Follow correct shutdown sequence per SOP (reduce load → stop combustion → cool).
- » Ensure cooling per procedure to avoid thermal shock to refractory.
- » Secure fuel supply per procedure; confirm no post-shutdown leaks.
- » Shut down fans per sequence; check bearing vibration/temperature after stopping.
- » Record final shift parameters: temperature, incidents, maintenance recommendations.

CL-05. Abnormal & emergency situation checklist

In case of abnormalities, prioritize safety and follow interlocks for shutdown if needed.

- » Flame loss/unstable combustion: Execute safe shutdown, purge per procedure, investigate cause.
- » Overtemperature/large temperature swings: Reduce load, check sensors and controls.
- » Fuel/gas leak: Isolate source, secure area, follow leak procedure.
- » Black smoke/high CO (if monitored): Check for insufficient air/incomplete combustion, adjust per SOP.
- » Severe fan vibration/abnormal noise: Shut down for mechanical check to prevent major damage.
- » Fire alarm/electrical fault: Activate emergency stop, follow fire safety/electrical safety procedures.
- » Record incident details and generate maintenance request; classify severity (critical/moderate/minor).

CL-06. Periodic Maintenance Checklist for Industrial kiln and furnace system (for reference)

General Info: Plant ___ | Area ___ | Kiln ID ___ | Kiln Type ___ | Fuel ___

Maintenance Period: [] Weekly [] Monthly [] Quarterly [] Yearly | Date ___

Performed by: ___ | Supervised/Approved by: ___

Principle: Items marked with "*" require kiln shutdown or equivalent safe conditions.

A. Fuel supply system

- » Check for leaks at piping/joints/valves; tighten if necessary.
- » Clean or replace fuel/gas filters as scheduled.
- » Check operation of safety valves/emergency shut-off valves (function test).
- » Check flow/pressure measuring devices (stable reading, needle not stuck).
- » Check material feeders (conveyor/screw/hopper): wear, jams, vibration. *
- » Check fuel storage tank/bunker: waterproofing, ventilation, fire safety, warning labels.

B. Combustion air – exhaust – ducting system

- » Check combustion/induced draft fans: vibration, noise, bearing temperature.
- » Check belts/couplings/alignment; tighten mounting bolts.
- » Lubricate bearings per manufacturer's recommendation.

- » Clean fan blades/ducts; check for dust buildup, blockages. *
- » Check air dampers/control vanes: binding, excessive play, full travel.
- » Check for air in-leakage at joints, flanges, and access doors.

C. Burner System & Combustion Chamber (if fuel-fired)

- » Check burners: cleanliness, soot deposits, nozzle condition. *
- » Check igniters/flame sensors: clean, test signal.
- » Check flame stability during test run: no pulsation/sudden extinction.
- » Test safety interlocks: flame failure, overtemperature, abnormal pressure (function test).
- » Inspect combustion chamber: cracks, deformation, slag buildup (if any). *

D. Kiln Shell – Doors – Insulation – Refractory Lining

- » Check door seals, gaskets, hinges/locks; replace if aged.
- » Inspect kiln shell for "hot spots"; mark abnormal locations for repair.
- » Inspect refractory lining: cracks, spalling, local erosion. *
- » Check expansion joints, anchors; tighten/repair per technical recommendations. *
- » Clean door areas/tracks/product entry/exit equipment. *

E. Instrumentation & Control System (PLC/SCADA if applicable)

- » Calibrate/check temperature sensors per plan (especially critical zones).
- » Check excess O₂/pressure/flow sensors (if any): clean probes, test signal.
- » Test alarm signals and emergency stop buttons: function test, record result.
- » Inspect control panels: dust/moisture, cooling fans, terminals, grounding; tighten connections. *
- » Backup control configuration/operational program (if applicable), control access permissions.

F. Heat Recovery Equipment (if any)

- » Check inlet/outlet temperature differential; note efficiency decline trend.
- » Check for dust/fouling buildup; plan cleaning based on threshold. *
- » Check for cross-leakage (flue gas – air/water) and seal integrity at joints. *
- » Check pumps/valves/hot water piping (if any): leaks, vibration, cavitation.

G. Flue Gas Treatment Equipment (if any)

- » Record filter/device differential pressure; compare to allowable limit.
- » Check for leaks in flue ducting, access doors, inspection ports. *
- » Check induced draft fan, stack: deposits, corrosion, vibration. *

- » Check dust collection system (hopper, screw conveyor, container): no blockages.

*

H. Maintenance Records – Corrective Actions

- » Update maintenance log: items, parts used, downtime, personnel.
- » Note unresolved abnormalities and action plan (target date, responsible person).
- » Perform root cause analysis for recurring issues (leaks, rapid fouling, unstable combustion...).

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