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Solutions to increase the use of alternative fuels in cement clinker production

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Technology
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ABSTRACT

This article presents an overview of the research and application of technical solutions, technologies, and equipment for processing and utilizing domestic, medical, agricultural, and industrial waste containing energy. The goal is to increase the use of alternative fuels, conserve resources, and reduce environmental pollution through co-processing in cement clinker factories. This approach aligns with the current global and regional development trend, especially as energy costs rise and fossil fuel resources become increasingly depleted.

1. Introduction

The cement industry consumes significantly more energy than many other sectors, with electricity costs accounting for a large portion of production expenses. As a result, energy conservation and emission reduction have become key development priorities for the cement industry. This focus also aligns with the future direction of Vietnam's cement industry, which aims to use mineral resources efficiently, conserve energy, and reduce emissions. Additionally, the industry seeks to integrate production with recycling, waste reuse, waste treatment, and environmental protection efforts.

According to Vietnam's Construction Materials Development Strategy for 2021-2030, approved by the Prime Minister, the goal is to use alternative fuels for up to 15 % of the total fuel consumption in cement clinker production. By 2050, this target is expected to increase to 30 %, achieved through the recycling and utilization of municipal solid waste, agricultural waste, and industrial waste [11].

2. Global Context

It is estimated that the cement industry accounts for approximately 12-15 % of the total energy consumed by the industrial sector globally [12]. According to the International Energy Agency (IEA), the share of alternative fuel use in cement production is projected to reach about 11 % by 2030 and increase to 23 % by 2050 [9].

The use of alternative fuels varies significantly across countries. Globally, the cement industry averages 4.3 % alternative fuel usage, but in some regions, the rate is much higher. In the United States, for example, alternative fuels can constitute between 20 % and 70 % of the total energy required for production. In Europe, the Netherlands leads with over 83 % of its cement production energy derived from alternative fuels, while other European countries report usage rates ranging from 22 % to 62 %. In Japan and Germany, the use of alternative fuels for thermal energy in cement production reached 64.6 % in 2015.

The Basel Convention (2011) defines co-processing as "the use of waste in production processes with the aim of recovering energy and/or resources and, as a result, minimizing the use of conventional materials and/or resources through substitution" [10]. This approach is increasingly being adopted worldwide to reduce reliance on fossil fuels, improve sustainability, and minimize environmental impact.

3. Domestic Situation and Trends in the Use of Energy-Containing Waste as an Alternative Fuel in Cement Plants

The cement industry in Vietnam is facing unprecedented challenges due to the reliance on fossil fuels, particularly coal, which is becoming increasingly scarce. In response to this situation, domestic cement plants have not only shifted to using lower-calorific-value coal but are also increasingly adopting energy-containing waste as an alternative fuel.

Currently, the primary sources of alternative fuels include waste from industries such as leather, footwear, textiles, and packaging. These materials often consist of waste fabric, leather scraps, packaging casings, and similar by-products. Additionally, agricultural waste, such as rice husk ash and cashew shells, is being utilized due to its high calorific value, exceeding 4500 kcal/kg.

Industrial and agricultural waste with high calorific values, along with large quantities of municipal solid waste, are now being widely explored and processed for use as alternative raw materials and fuels in cement clinker production. This shift not only addresses the issue of resource depletion but also contributes to more sustainable production practices in the cement industry.

4. Research and Results Achieved in Vietnam

Several cement plants in Vietnam are currently conducting research and testing the feasibility of using alternative fuels derived from solid industrial waste, such as waste from the leather, footwear, and textile industries. Notable plants involved in these efforts include No Son Cement, Hoang Thach Cement, Halong Cement, Ha Tien Cement, and Lam Thach Cement, among others. According to statistics, alternative fuels are primarily being combusted in calciners.

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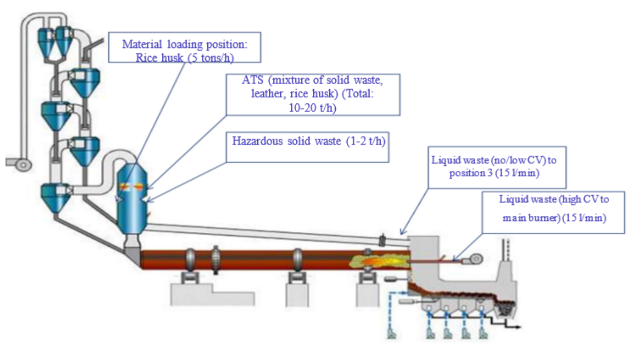
The INSEE cement plant in Hon Chong, Kien Giang, has also successfully utilized a variety of waste materials, including waste from the shoe industry, waste oil, hazardous solid waste, and rice husk ash, as alternative fuels in its cement kilns. These initiatives demonstrate that in cement production, many types of combustible waste, especially solid waste containing energy, can be effectively recycled and burned in rotary kilns, contributing to more sustainable production practices.

+ Alternative Fuel material loading position at Hon Chong Cement Plant (INSEE)



Currently, all cement plants utilize alternative fuels, which are primarily combusted directly in calciners with a substitution rate of approximately 30 %. These plants can only process waste with a high calorific value (> 4500 kcal/kg) and low moisture content (< 5 %). At present, no plant is equipped to handle waste with low calorific value and high moisture, such as municipal waste, which is used in other countries.

Industries that engage in waste co-processing include:

- Thermal Power: Uses waste in combustion processes to enhance recycling and reduce the reliance on non-renewable fuels.

- Metallurgy: Incorporates waste processing in furnaces to improve resource efficiency.

- Cement Industry: Benefits from co-processing due to the following advantages:

+ Utilizes high-temperature kilns that are well-suited for waste processing.

+ Capable of burning a wide range of waste materials.

+ Achieves high levels of heat recovery.

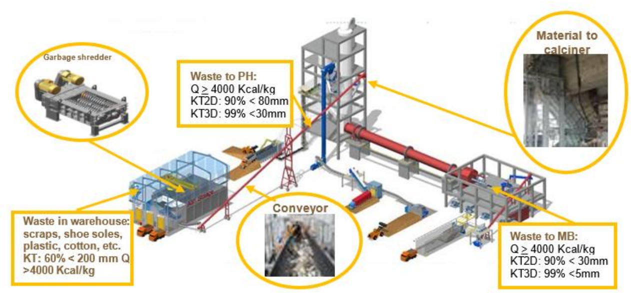
+ Requires minimal waste component classification, generates no ash or slag, and maintains environmental safety.

5. Brief description of waste co-processing technology in the cement industry

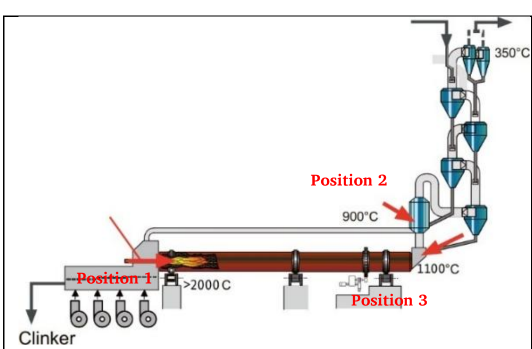
Today, the cement industry worldwide uses two technological models for waste co-processing:

Direct processing technology:

The raw waste will be delivered to the cement plant yard where it will be classified, mixed, cut and finely ground to stabilize its size and calorific value before being fed to the calciner or main burner.



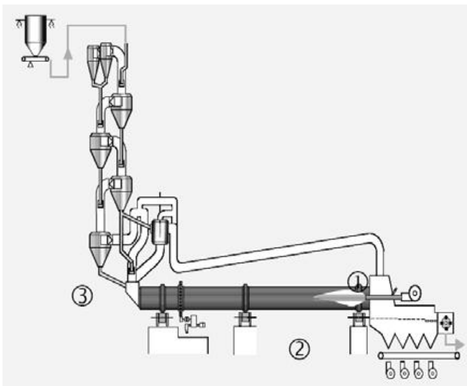
+ **Loading location and place:** Suitable loading location and place depend on the following factors: waste type; pregerter and calciner type/shape...



- **Position 1:** Main burner at the outlet of the rotary kiln (with carbon nozzle)
- **Position 2:** Burnt in the calciner.
- **Position 3:** Kiln Tail - Rotary Kiln Entrance Feeder (Material from C1 enters the rotary kiln)

N$_o$	Characteristic	Unit	Loading position		
			Location 1	Place 2	Location 3
1	Some kind of trash		Crystal (earth)	Raw (ground)	Coarse (very rough)
2	Size	mm	≤ 25	≤ 100	≤ 250
3	Heat treatment	Kcal /kg	≥ 4000	≥ 2000	Short
4	Burning time	h	6-8	2-7	-
5	Combustion method		Spray the furnace head, burn when exposed to furnace gas.	Pour into a calciner and burn with flue gases.	Ignites when exposed to flue gases containing oxygen. Slow combustion at the end of a rotary kiln (install an additional combustion chamber)

+ Characteristics of temperature and holding time in the furnace system



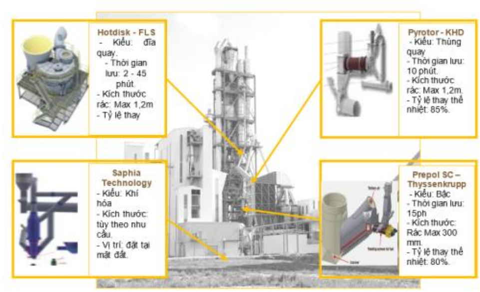
Characteristic	Temperature and time
Temperature at the main burner (1) of the rotary kiln (2)	>1450 ^{0}C (material) >1800 ^{0}C (flame temperature)
Storage time on main burner	>12-15 sec >1200 ^{0}C >5-6 sec >1800 ^{0}C
Pre-calcination device temperature (3)	>850 ^{0}C (material) >1000 ^{0}C (flame temperature)
Burning time with pre-calcination	> 2-6 s > 800 ^{0}C

+ Advantages of Burning Solid Waste in Cement Kilns:

- Partial Substitution for Traditional Fuels: The heat generated from burning solid municipal waste can partially replace traditional fuels, such as coal, in the clinker firing system.
- Effective Destruction of Organic Pollutants: The rotary kiln's burner flame can reach temperatures up to 1800 ˚C, with the adhesion zone at 1450 ˚C and a residence time exceeding 8 seconds. These conditions ensure the effective destruction of organic pollutants.
- Absorption of Acid Gases: Cement kilns can absorb acid gases produced during combustion, such as HF, HCl, and SO_2. These gases react with alkaline products generated during clinker production, reducing their impact and ensuring they do not adversely affect cement quality.
- Complete Oxidation and Safe Handling of Heavy Metals: Municipal solid waste is fully oxidized in the rotary kiln, with heavy metals securely incorporated into the clinker, preventing their release into the environment. The ash and slag from this process can be used as raw materials for clinker production, minimizing secondary waste generation.
- Reduction in Landfill Use and Pollution: Using solid waste in cement kilns decreases the need for waste landfilling and contributes to reducing environmental pollution.

Indirect processing technology:

All types of solid waste such as tires, bulky waste, etc. will be transported and burned in an external combustion chamber (newly installed outside the furnace system).



Rate Advantages of waste recycling technology

Direct waste treatment	Indirect waste treatment
Advantage: Shredding waste enhances homogeneity, stabilizes calorific value, and improves flow rate during combustion in a furnace compared to untreated waste. Shredded waste can be utilized in various locations within the kiln system, including the kiln head. The co-combustion of waste with raw powder increases heat transfer efficiency and stabilizes the chemical composition of the resulting clinker.	Advantage: A diverse range of waste types can be utilized, including household waste, tires, and untreated industrial waste. It accommodates waste with lower calorific values and higher moisture content. No significant investments are required for a shredding system, nor is there a need to repair the heat exchanger tower. Combustion occurs externally to the calciner, minimizing its impact on the overall combustion process.
Disadvantages: The implementation of an additional waste shredding system necessitates significant investment. Only classified household waste is suitable for this method. Depending on the system design, if more than 25% of the waste is incinerated in the calciner, the heat exchanger tower system may require repairs.	Disadvantages: This method incurs high initial investment costs. It requires substantial space within the heat exchanger tower area. There is less efficient utilization of waste energy and a higher volume of exhaust gas generated. Greater variability in chemical composition and calorific value complicates the control of the clinker melting process.

6. Implementation of Technological and Hardware Solutions to Increase Alternative Fuel Consumption in Cement Clinker Kilns

Since the furnace of the existing process equipment line is not designed to burn alternative fuel sources, the amount of alternative fuel supplied to the system is limited to a certain limit. Usually, the amount of alternative fuel supplied to the calciner is about 30 % (due to the volume limit of the oven). Therefore, it is necessary to add technological solutions and auxiliary combustion equipment to the system to increase the share of alternative fuels in the production of cement clinker. Modern types and types of secondary combustion chambers are diverse, such as: stage combustion, rotating disk, rotating barrel, gasification.

The existing kiln equipment is not designed to handle large amounts of alternative fuels, typically limiting their use to about 30% due to capacity constraints. To increase this share, it is essential to integrate advanced technologies and auxiliary combustion systems. Modern options include: Stage Combustion Chambers, Rotating Disk Chambers, Rotating Barrel Chambers, Gasification Chambers.

These technologies can enhance fuel flexibility and improve the integration of alternative fuels in cement production.

- Indirect combustion solution using PYROROTOR technology from KHD.

+ *Characteristics:*

- Burning of untreated waste: truck tires, pieces of tires... large sizes;
- Use wind 3 from the clinker cooler for heating;
- Additional installation into an existing furnace system is possible;
- Easy to operate.

+ *Operating principle:*

The replacement fuel is introduced into the burner (rotating cylinder type) and starts burning under fully oxidizing conditions under the influence of hot tertiary air. The burning fuel is transported from the beginning of the combustion chamber to the exit of the combustion chamber by means of a rotating combustion chamber system. The hot gas, the remaining ash and part of the burnt material are fed through a pipeline to the clinker burning system.

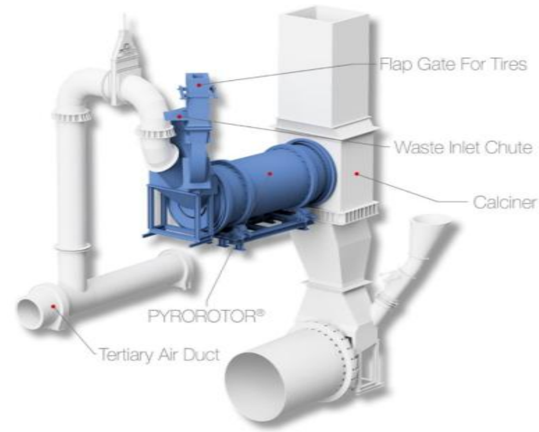


Fig. 1. KHD PYROROTOR device.

- Indirect combustion solution using HOTDISC technology from FLSmidth.

+ *Characteristics:*

- Diversify waste sources, types and sizes of waste used: sewage sludge, truck tires, etc.
- Use wind 3 from the clinker cooler for heating;
- Additional installation into an existing furnace system is possible;
- Fast and easy maintenance.

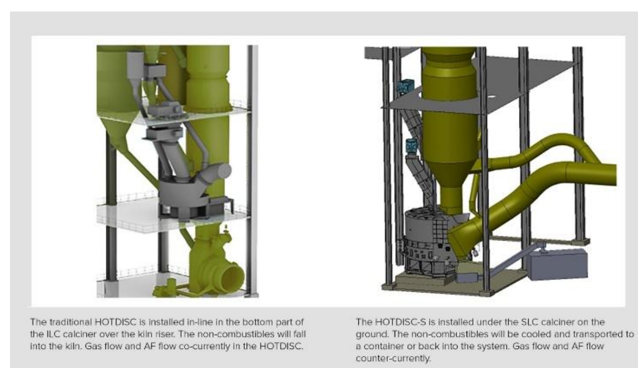


Fig. 2. HOTDISC device from FLSmidth.

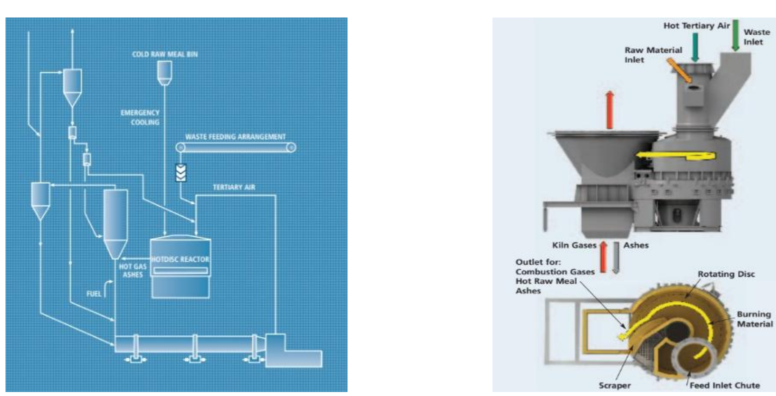


Fig. 3. The structure and operating principle of the HOTDISC device.

+ *Operating principle:*

The reserve fuel is introduced into the slowly rotating disk and begins to burn under fully oxidizing conditions under the influence of hot tertiary air. The combustion fuel is transported approximately 270 ^{0} along the disk until it reaches the stripper, where the remaining ash and some of the combustion material are ejected into the channel.

The heavy burnt residue enters the furnace inlet, while the lighter residue and flue gases move into the furnace.

- Indirect combustion solution using the PREPOL SC combustion chamber from POLYSIUS

Characteristics

Versatile Waste Handling: Accommodates a wide range of waste sources, types, and sizes.

Simple Processing: Straightforward processing procedures.

Utilizes Waste Heat: Uses wind from the clinker cooler for heating.

Retrofit Capability: Can be integrated into existing furnace systems.

No Moving Parts: The combustion zone is devoid of mechanical components.

Customizable Design: Tailored to production scale and waste types.

High Fuel Volume Capacity: Capable of replacing over 50 % of kiln fuel in systems with a capacity of 6,000 tons of clinker/day.

Efficient Maintenance: Designed for fast and easy upkeep.

Alternative Fuel

Diverse Fuel Options: The system supports a variety of alternative fuels, including those with low calorific values and high moisture content, expanding the range of usable waste materials.

High Efficiency: Optimized for large volumes of alternative fuels, enhancing overall efficiency and sustainability in cement production.

Fig. 4. Alternative fuels.

+ *Operating principle:*

The Staged Combustion Chamber (SC) is designed to handle a wide range of alternative fuels, including those with low calorific value. It provides flexibility and operational reliability by utilizing a unique transport mechanism without mechanical transmission elements. Fuel is first loaded into the chamber via a screw conveyor, which lifts it to the initial stage. Here, hot air heats the fuel, releasing volatile substances. The fuel is then moved through subsequent stages using pulse nozzles, with each stage equipped with 5-7 nozzles for efficient processing.

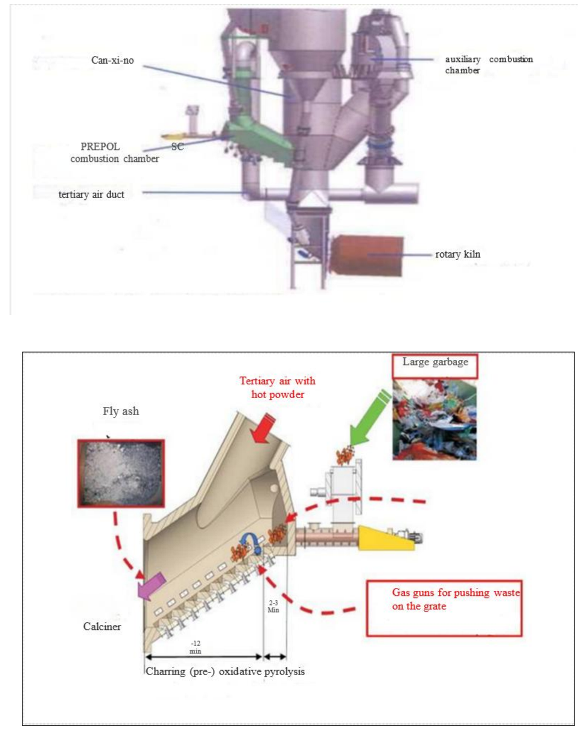


Fig. 5. Polysius PREPOL device.

- Indirect combustion solution using Saphia gasification technology

+ *Characteristics:*

Versatile Waste Handling: Accommodates diverse types and sizes of waste.

Simplified Processing: Straightforward processing steps.

Utilizes Waste Heat: Uses wind from the clinker cooler for heating.

Retrofit Compatibility: Can be added to existing furnace systems.

No Moving Parts: The combustion zone is free from mechanical components.

Customizable Design: Tailored to production scale and waste types.

High Fuel Volume Capacity: Suitable for replacing over 50% of kiln fuel in 6,000-ton clinker/day systems.

Easy Maintenance: Quick and uncomplicated upkeep.

+ *Operating principle:*

Operating Principle

Biogas combustion technology, generated through the pyrolysis of biomass materials like wood, rice husks, and agricultural by-products, produces combustible gases (CO, H_2, CH_4). This gasification process yields high productivity and is well-suited for large-capacity cement clinker production lines.

Compare and evaluate the technology of combustion chamber auxiliary equipment manufacturers.

TT	Element	The company designs and manufactures auxiliary equipment for the combustion chamber.			
		Saphia Equipment (India)	PYROROTOR equipment KHD (Germany)	HOTDISC device by FLSmidth (Denmark)	PREPOL equipment from Polysius (Germany)
1	Place of installation of the combustion equipment in the combustion system	Earth	Tail of a rotary kiln or calciner	Calcifier	Tail of a rotary kiln or calciner
2	Type/shape of combustion equipment	Gasification	Rotating barrel	Rotating disc	Record level
3	Combustion chamber	-	There are moving parts in the hot zone.	There are moving parts in the hot zone.	There are no moving parts in the hot zone.
	- Combustion chamber design	Takes up space and area	Takes up space and area	Compact (saves space and area)	Compact (saves space and area)
	- Durability	High	High	High	Higher
	- Heat control	Good	Good	Good	Better
	- Ability to burn completely in the combustion chamber.	Good	Good	Good	Better
4	Performance	High	Easy to adjust (barrel tilt and rotation speed - holding time matches input fuel characteristics)	Easily adjustable (feed rate and rotating disc - retention time matches input fuel characteristics)	High performance, easy adjustment (gas feed rate and pressure, air injection frequency – holding time corresponding to the characteristics of the input fuel)
5	Design, production	Difficult	Difficult	Difficult	Less complex
6	Requirements for manufacturing materials	High	High	High	No high demands, easy to satisfy
7	Installation and connection to the clinker firing system	Easy	Easy	Easy	Easy
8	Fuel has been delivered				
	- Type	More variety	More variety	Diversity	More variety
	- Size	Wide range of sizes, no need for significant processing or pre-treatment.	Wide range of sizes, no need for significant processing or pre-treatment.	Wide range of sizes	Wide range of sizes, no need for significant processing or pre-treatment.
9	Work				
	- Control system	Automated, easy to customize	Automated, easy to customize	Automated, easy to customize	Automated, easier to set up
	- Reliability and stability	High	High	High	Higher
10	Maintenance and repair	Difficult	Difficult	More complex	Easy to maintain – low cost.

7. Conclusion

- Global and national research indicates a growing trend towards replacing fossil fuels with energy-containing solid fuels in cement production. This transition is both necessary and feasible, offering notable technical, economic, and environmental benefits. By utilizing diverse waste sources, the industry can conserve resources, reduce energy consumption, and mitigate environmental impact.
- Aligned with the Prime Minister's Decision No. 1266/QD-TTg and commitments from COP26, Vietnam is advancing technology for the indirect combustion of municipal and industrial solid waste in

cement kilns. This development aims to replace traditional fuels with high-energy content waste, enhancing efficiency and sustainability.

- Vietnam, with 86 cement plants and a capacity of 110 million tons, ranks 4th globally. Many of these plants are well-positioned to adopt alternative fuels, promoting resource conservation and operational efficiency. Future investments should consider raw material availability, equipment compatibility, and technological solutions to optimize economic returns and support sustainable industry practices.

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