

# International Cementreview



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# Improving efficiency while cutting emissions

Waste heat recovery systems have emerged as a practical solution to support decarbonisation in the cement industry. However, the introduction of such systems is often a first-of-its-kind investment, with risks and costs attached. Modular WHR solutions offer a scalable, lower-cost pathway with a range of advantages.

■ by *Exergy, Italy*

The cement industry is faced with mounting decarbonisation challenges under increasingly stringent regulatory frameworks, rising carbon prices and more ambitious net-zero commitments from governments, investors and industry stakeholders. Regional and national policies are progressively compelling the adoption of low-carbon technologies and energy-efficient practices across heavy industrial sectors.

In the European Union, leading cement producers have committed to reducing Scope 1 (direct) CO<sub>2</sub> emissions per tonne of cement by approximately 30 per cent by 2030 compared to 1990 levels, primarily through improvements in thermal energy efficiency and fuel switching. According to the GCCA's Cement and Concrete Industry Roadmap, in the 2020-30 period, unlocking significant emission reductions will depend heavily on energy efficiency interventions in parallel with alternative fuels, carbon capture utilisation and storage and demand-side management measures.

Within this evolving policy and market context, waste heat recovery (WHR) technologies emerge as highly relevant, offering a practical, technically mature and immediately deployable pathway to reduce energy intensity, operational costs and carbon emissions. Nevertheless, adoption remains uneven across global regions, reflecting a combination of market, regulatory and operational factors.

## Evolving WHR adoption patterns across global cement markets towards 2030

The adoption of WHR systems in cement production has gained notable momentum over the last decade. Historical analyses indicate that by 2022, the installed WHR

capacity in the cement sector reached approximately 2.5GW<sub>e</sub> and forecasts suggest a compound annual growth rate of 11.8 per cent through 2032, potentially increasing total capacity to 7.5GW<sub>e</sub> under favourable market conditions. However, growth is highly region specific, influenced by regulatory frameworks, energy pricing, plant modernisation opportunities and the pace of industrial development.

In the Asia-Pacific region, led by China, India and southeast Asian countries, WHR installations are expected to dominate global growth to 2030, driven by escalating energy costs, large-scale new plant construction and policy frameworks incentivising decarbonisation. In Europe growth is expected to be moderate but steady, mainly through retrofitting of

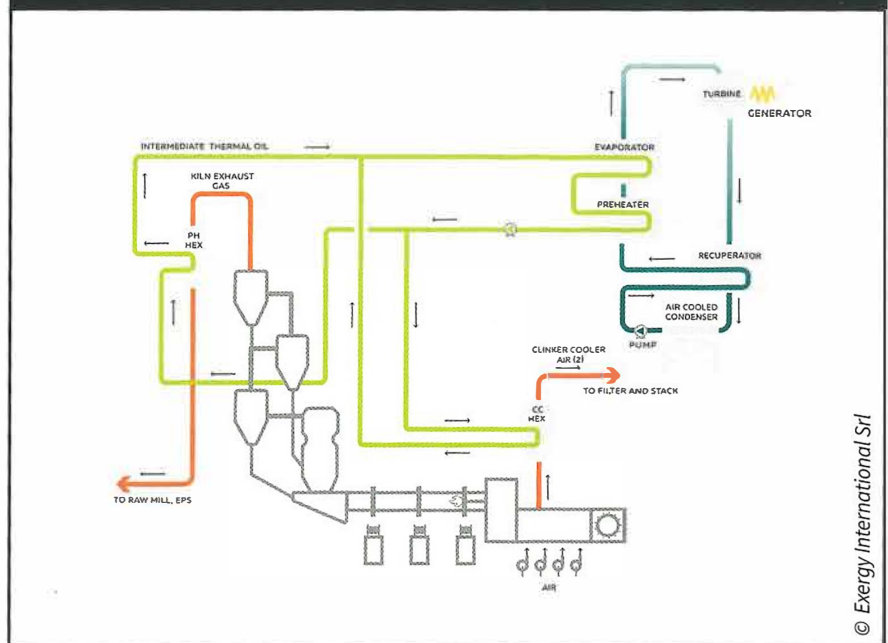
existing facilities and optimising energy efficiency in mature installations. Adoption in the Middle East, Latin America and Africa is more localised and occurs primarily in plants facing high energy costs or grid instability.

## Factors slowing WHR adoption in the cement sector

Despite its proven technical maturity and demonstrated energy-saving potential, several factors continue to limit the widespread deployment of WHR systems in the cement sector. These barriers combine both genuine implementation challenges and perceived risks from plant operators that can delay investment decisions.

High upfront capital expenditure is a frequent constraint, particularly in regions

Figure 1: A standard WHR system employs an intermediate heat transfer loop that isolates the ORC cycle from abrasive exhaust gases. Heat exchangers capture the energy, transferring it to a thermal oil circuit which is then directed to the ORC evaporators.



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with low electricity tariffs or where fiscal incentives for energy efficiency are limited. Furthermore, WHR systems are wrongly often perceived as intrusive by plant owners, who are worried that these can lead to potential shutdowns. For many operators, the introduction of a WHR project constitutes a first-of-its-kind investment. Uncertainties regarding technology maturity, reliability and O&M requirements can further slow decision-making.

In smaller plants or those with limited waste heat gradients, the incremental energy recoverable may not justify investment, highlighting economy of scale as a significant barrier.

However, by adopting a highly tailored approach, offering modular or pilot-scale solutions, performance guarantees and consultative engineering support, WHR technology suppliers and integrators can help mitigate and overcome both real and perceived challenges from plants operators.

### Integration and technical design considerations

Organic Rankine cycle (ORC) systems provide a flexible and viable solution to overcome several of these barriers to WHR adoption. By operating as fully stand-alone power generation modules, ORC plants eliminate operational interference with core cement production equipment (eg kilns, preheaters and clinker coolers), thereby mitigating risks of operational disturbance and process derating. Additionally, modular design enables gradual deployment, allowing operators

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to start with smaller capacity units and scale up in subsequent phases while maintaining reliable electricity production for on-site consumption in locations with grid instability or difficult access to the network.

In a standard design, WHR systems employ an intermediate heat transfer loop that isolates the ORC cycle from dusty and abrasive exhaust gases. Heat exchangers capture energy from the preheater and clinker cooler exhaust streams, transferring it to a thermal oil circuit, which is then directed to the ORC evaporators. The design of heat exchangers accounts for dust content, particle abrasiveness, gas velocity, dust stickiness, operating pressure, temperature gradients and required cleaning systems, ensuring long-term reliability and high heat transfer efficiency. Parallel or series thermal fluid loop arrangements may be implemented depending on plant layout and specific heat availability.

Within the ORC cycle, the working fluid – typically cyclopentane, although refrigerants can be selected where non-flammable fluids are required – is pressurised, preheated, vaporised and expanded through a turbine. The exhaust vapour is condensed either through an air-cooled condenser, ideal for water-scarce regions, or a water-cooled condenser where sufficient cooling water is available. Control, instrumentation, pumps, cooling fans, safety systems and electrical interfaces are fully integrated with the plant’s existing automation architecture to ensure synchronised operation and high availability.

### ORC advantages

When addressing both the real and perceived barriers to WHR implementation, ORC systems demonstrate unique technical, operational and economic advantages.

### Technical advantages

- ability to exploit low- to medium-temperature heat sources ( $\geq 150^{\circ}\text{C}$ ) efficiently
- high flexibility and efficiency under off-design and partial-load conditions

**Table 1: CO<sub>2</sub> emission reductions achievable when using WHR systems**

Case	MW <sub>th</sub>	MW <sub>e</sub>	CO <sub>2</sub> saved (tpa)
1	25	6.25	25,200
2	40	10	29,100
3	16	4	11,600

- elimination of blade erosion risk from condensation, as occurs in steam cycles, hence low maintenance requirements
- reduced or no water consumption, particularly with air-cooled condensers
- stand-alone operation with minimal integration risk to core production equipment
- automated operation and remote-control system.

### Economic advantages

- lower maintenance costs compared with steam-based WHR systems
- reduced operating costs via electricity generation offsetting plant energy consumption
- improved ROI, especially when coupled with carbon credits, incentives or feed-in tariffs
- modular, scalable design enabling incremental investment and phased capacity deployment.

### Environmental and operational advantages

- reduction in energy consumption, potentially supplying up to 30 per cent of plant energy needs
- improved energy efficiency contributing to decarbonisation goals
- reduction in CO<sub>2</sub> emissions associated with energy consumption
- avoidance of water withdrawal in water-scarce locations.

When considering CO<sub>2</sub> emission reductions achieved through the avoided use of fossil-fuel-derived electricity, the environmental and economic benefits of a WHR ORC system become particularly significant. In jurisdictions where carbon pricing mechanisms, taxes or emission trading schemes are in place, the avoided CO<sub>2</sub> emissions directly translate into reduced compliance costs and enhanced economic performance.

Table 1 provides indicative figures for the CO<sub>2</sub> emission reductions achievable under different plant configurations based on 25 per cent plant efficiency.

In summary, the combination of technical flexibility, operational independence, and modularity makes ORC systems particularly well suited for WHR applications in cement plants, supporting both energy efficiency and emission reduction objectives.

### Modular ORC systems for the cement plant

Exergy has positioned itself as a leading supplier of tailor-made ORC systems for cement plants worldwide, optimising each installation to achieve maximum cycle efficiency while accommodating specific project requirements. The company's capabilities include:

- advanced cycle optimisation, selection of working fluids and incorporation of reheating systems for maximum energy recovery
- proprietary Radial Outflow Turbine (ROT) technology or alternative expanders adapted to the thermal profile
- modular preassembly on skids or in containerised units for streamlined transport, installation and reduced

Figure 2: Exergy's OCR-Lite WHR system is a compact, cost-effective and modular solution, enabling cement plants to introduce WHR as a pilot or demonstration project



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- on-site construction
- integrated control systems, safety architectures, and remote monitoring
- performance guarantees, life cycle support, and after-sales service.

#### ORC-Lite

To support pilot or demonstration projects and reduce upfront investment, Exergy has

developed the ORC-Lite series, a compact, cost-effective and modular solution (see Figure 2).

Key features include:

- single 1.1 MW<sub>e</sub> high-temperature modules (up to 310°C at ORC inlet), deployable in dual or multiple configurations
- compact footprint (25x12x9m) for

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**Table 2: ORC-Lite technical specification for various source conditions**

Hot oil (Therminol 66)	310°C		300°C		280°C		250°C	
Heat source inlet temperature (°C)	310	310	300	300	280	280	250	250
Heat source outlet temperature (°C)	150	150	150	150	150	150	150	150
Heat source flow rate (tph)	48.9	47.6	52.6	50.7	63.4	60.1	88.6	83.1
Air temperature (°C)	20	10	20	10	20	10	20	10
Gross power (kW)	1100	1100	1100	1100	1100	1100	1100	1100
Net power (kW)	1000	1000	1000	1000	1000	1000	1000	1000

**Table 3: hot-source and thermal oil nominal conditions for Kiln Lines 1 and 2**

Source	Exhaust flow (Nm <sup>3</sup> /h)	Inlet temperature (°C)	Recovered heat (kW <sub>th</sub> )	Thermal oil temperature in/out (°C)
<b>Kiln Line 1</b>				
Cooler to ESP	105,600	330	8,670	85 / 301
Condensing tower	160,200	385	13,350	130 / 316
<b>Kiln Line 2</b>				
Cooler to ESP	135,800	310	10,085	85 / 279
Condensing tower	158,000	362	11,260	130 / 298

limited-space installations

- cyclopentane as the standard working fluid
- modular, plug-and-play system
- reduced commissioning time and lower base turnkey cost, suitable for small demonstration projects before full-scale deployment.

This dual-offering strategy of full custom large ORC and modular ORC-Lite enables Exergy to offer the broadest array of WHR systems to meet market needs and accelerate market penetration.

### Exergy case studies

Exergy has successfully implemented 11 WHR projects in energy-intensive sectors, including the cement, steel, glass and chemical industries.

In the cement sector, a notable recent project studied by Exergy involved a 10MW<sub>e</sub> ORC in Europe recovering energy from both the preheater and clinker cooler exhausts of two kiln lines (see Table 3). Preheater exhaust temperatures ranged between 362-385°C with flow rates between 158,000-160,200Nm<sup>3</sup>/h, while clinker cooler exhausts were in the range of 310-330°C with flows of 105,600-135,800Nm<sup>3</sup>/h.

The system transfers approximately 43MW<sub>th</sub> of thermal energy through a thermal oil circuit, generating roughly 10.8MW<sub>e</sub> gross with an ORC efficiency of 25 per cent and >97 per cent availability, employing an air-cooled condenser and Exergy's ROT.

### Conclusion

WHR systems represent a proven and efficient pathway for decarbonising the cement sector, offering measurable reductions in fossil fuel consumption, electricity costs, and CO<sub>2</sub> emissions. ORC solutions, in particular, provide exceptional operational flexibility, minimal maintenance requirements, and compatibility with both high- and medium-temperature heat streams. Their stand-alone configuration ensures no interference with cement production,

mitigating operational risks typically associated with process-integrated solutions. As the cement sector faces tightening regulatory requirements, rising energy costs and competitive pressures, the deployment of WHR ORC systems provides both environmental and economic benefits, supporting compliance, energy efficiency and long-term competitiveness. Technology providers with proven industrial expertise and the ability to customise solutions to plant-specific conditions play a pivotal role in enabling rapid, reliable and efficient WHR adoption across the global cement industry. ■

**Figure 3: Exergy installed a WHR system at Cementi Rossi, Italy**