From waste heat to Watts

Waste heat to power technology for alternative power generation has developed significantly in recent years, evolving into systems that are suitable not only for cement production but also pave the way for their employment in cement plants with carbon capture facilities.

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The global cement industry is facing one of its most critical sustainability challenges: how to meet the demand for cement while drastically reducing the CO_2 emissions generated during its production.

As of early 2024, approximately 145 countries had either committed to or were actively considering net zero targets. In Europe this ambition is typically framed as achieving net zero emissions by 2050.

Yet, according to the International Energy Agency, the direct CO_2 intensity of cement production, defined as the amount of CO_2 emitted per tonne of cement produced, has remained virtually unchanged over the past five years. This stagnation is in sharp contrast to the four per cent reduction annually required through 2030 to align with the net zero emissions by 2050 scenario.

Waste heat as power source

In light of this urgent need to reduce emissions, improving the energy efficiency of cement plants stands out as one of the fastest and most effective strategies to lower global fuel consumption and reduce Scope 2 CO_2 emissions (ie, indirect emissions from purchased energy). Among the available solutions, waste heat recovery (WHR) or waste heat to power (WHP) systems offer one of the most direct and impactful approaches to enhancing the energy efficiency of the clinker production process.

By capturing thermal energy from hot exhaust gases generated during clinker production, WHP systems can produce up to 30 per cent of the electricity required by a cement plant. Without such systems, this valuable energy is not only wasted, but also additional resources such as water or electricity must be consumed to cool and process these streams. Thus, implementing WHP not only reduces environmental impact but also improves operational efficiency and cost-effectiveness.

A Turboden ORC power plant built for Sönmez Çimento in Turkey. In operation since 2020, the unit generates 7.3MW_e by exploiting preheater exhaust gases and hot air from the clinker cooler

ORC process description

Over the past 15 years, the cement industry has increasingly embraced organic Rankine cycle (ORC) technology as a dependable and competitive alternative to the conventional steam Rankine cycle (SRC) for heat to power applications. This shift has been driven by continuous innovation in ORC systems, enhanced economic viability and a growing global focus on sustainable industrial solutions.

Cement plants typically have two sources of recoverable thermal power that can be utilised through an ORC unit: exhaust gas from the preheater towers (PH) and hot air from the clinker cooler (CC).

The exhaust gas or hot air from the process enters a heat recovery exchanger, which transfers the thermal power in the gas stream to a thermal vector, typically thermal oil. The heat exchanger is designed to effectively handle the gas stream's specific conditions, managing emissions and dust commonly present in the gas. The thermal vector then transfers the thermal power to the ORC working fluid, often cyclopentane for cement plant applications (being the working fluid that best fits with the thermal source characteristics in terms of temperature). The cyclopentane evaporates and enters the turbine, generating mechanical power, which is converted into electric power by a connected generator. The expanded vapour then passes through an internal heat exchanger – the regenerator, where it releases heat to its liquid phase coming from the opposite side. After the regenerator, the vapour enters the condenser, where it further cools down and returns to a liquid phase. This condensation can occur through a cooling water circuit or by utilising ambient air directly. In the latter case, there is no water consumption for ORC plant operation, a significant advantage in water-scarce regions. The ORC working fluid is then pumped back through the regenerator to the evaporator, completing its cycle.

Key benefits

Through capturing and utilising waste heat to generate electricity, or both electricity and thermal power, particularly in combined heat and power configurations where hot water at temperatures of up to 110°C can be produced, cement plants can enjoy several benefits, including:

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• **improving efficiency** – Implementing an ORC solution enables cement plants to enhance their overall energy efficiency by harnessing the thermal power generated during the production process that would otherwise be dissipated into the environment.

• **cost savings** – Installing an ORC system can result in cost savings for cement plants by reducing the energy they have to buy from the national grid (or produce with alternative methods such as ICEs) for the production plant operations, thus lowering energy bills. Additionally, cement plants which install an ORC unit can ideally lock in electricity prices for the entire lifespan of the system (>20 years), mitigating risks associated with energy market fluctuations. Moreover, waste heat to power levelised cost of energy is typically lower compared with other renewable energy sources such as solar or wind, which are not constant and depend on external conditions. By using an ORC unit, cement plants can also cool down the gas produced while generating electric power, eliminating the need for electricity-consuming air-to-air heat exchangers or water in conditioning towers. This point is particularly relevant in countries where water scarcity is a real problem.

• **reducing fossil fuel consumption in cement plants with power plants** – The electricity produced by the ORC unit is used to feed part of the cement plant's internal loads, thereby reducing the need for energy generated through less environmentally friendly means. This leads to lower energy bills and decreases global carbon emissions.

• **enhancing competitiveness** – Cement plants that prioritise sustainability and energy efficiency are better positioned to compete in a market increasingly focussed on these aspects. By demonstrating a commitment to reducing their carbon footprint, cement plants can distinguish themselves as environmentally responsible and forward-thinking enterprises, thereby enhancing their competitiveness in the industry.

• **environmental benefits** – By reducing energy consumption and carbon emissions through ORC technology,

Table 1: Turboden reference projects in cement plants

Customer	Start-up	Kiln capacity (tpd)	Heat source	Heat carrier	ORC gross electric power (kW)
Ciments du Maroc (Heidelberg Materials), Morocco	2010	5000	PH	thermal oil	2000
Holcim Romania, Romania	2012	4000	PH + CC	thermal oil + superheated water	4000
CRH Slovakia	2014	3600	PH + CC	thermal oil	5000
CarpatCement (Heidelberg Materials), Romania	2015	3500	PH + CC	thermal oil	3800
Jura-Cement-Fabriken (CRH Group), Switzerland	2016	3000	PH	superheated water	2300
Cementi Rossi, Italy	2018	3500	PH + CC	none – direct exchange	2000
Çimko (Sanko Group), Türkiye	2019	9500	CC	thermal oil	7000
Holcim Suisse Eclépens, Switzerland	2020	2300	PH + CC	thermal oil	1300
Sönmez Çimento, Türkiye	2020	6000	PH + CC	thermal oil	7300
SECIL, Portugal	2024	3800	PH + CC	thermal oil	7200
Cimpor (Souselas), Portugal	2025	4200	PH + CC	thermal oil	8400
Cimpor (Alhandra), Portugal	Under construction	3100	PH + CC	thermal oil	6200
Lafarge Emirates (Holcim Group) (Investor: ENGIE), UAE	2025	7500	PH + CC	thermal oil	10,000
Medcem, Türkiye	2025	10,000	CC	thermal oil	11,000
Çimsa Eskişehir, Türkiye	2025	4500	PH + CC	thermal oil	5900
Riyadh Cement Co, Saudi Arabia	Under construction	2 x 5000	PH + CC	thermal oil	12,600
Colacem Sesto Campano (Investor: Enel-X), Italy	Under construction	3000	PH + CC	thermal oil	2000
Holcim Obourg (GO4ZERO), Belgium	Under construction	6000	PH + CC oxy-fuel kiln	thermal oil	7500
Undisclosed customer in Türkiye	Under construction	3300	CC	thermal oil	3500
Undisclosed customer in Türkiye	Under construction	3300	CC	thermal oil	3500
Undisclosed customer in Türkiye	Under construction	3300	CC	thermal oil	3500

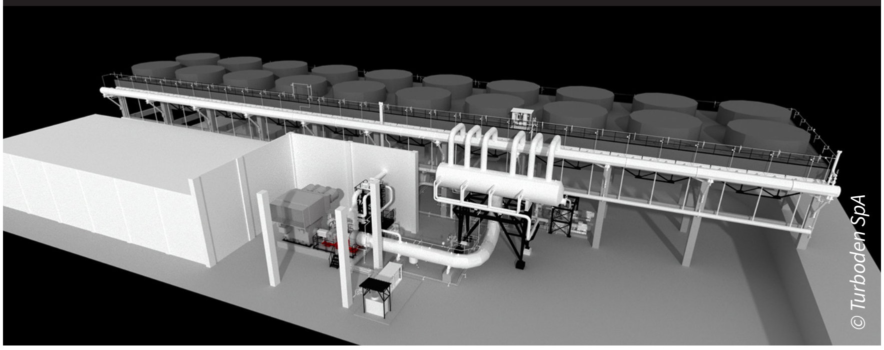

Figure 2: Turboden's largest ORC heat recovery power plant, under construction for Riyadh Cement Co, Saudi Arabia. The 13 MW_e project will support the kingdom's transition towards cleaner and more sustainable energy sources

cement plants can contribute to global efforts to mitigate climate change and minimise their impact on the environment.

Milestones past, present and future

Turboden offers ORC solutions ranging from 600kW_e to 40MW_e of electrical output from a single turbine, marking a significant expansion into power ranges traditionally dominated by SRC technology. This evolution positions ORC not only as a complementary solution but as a leading option for large-scale cement plants seeking efficient, water-free and low-maintenance waste heat to power systems.

Between 2024 and 2025, the company successfully secured six new projects exclusively within the cement industry, representing a combined installed capacity of over 35MW of clean electricity (see Table 1). This achievement highlights the growing appeal of waste heat to power via ORC technology as a strategic solution for cement plants aiming to reduce their carbon footprint.

In addition, since the beginning of 2025, Turboden has commissioned four ORC plants in the cement sector, further reinforcing its leadership in industrial energy efficiency.

Multi-kiln ORC facilities

A stand-out example is the 13MW ORC plant delivered to Riyadh Cement Co in Saudi Arabia (see Figure 2). This project demonstrates Turboden's ability to compete in power ranges traditionally dominated by SRC systems, especially in regions where water scarcity makes dry, closed-loop solutions such as ORC particularly advantageous.

The plant recovers heat from the preheater and clinker cooler gas streams of two 5000tpd clinker lines and is expected to generate more than 80GWh/year of clean electricity. This will result in a reduction of over 45,000tpa of CO_2 emissions, contributing meaningfully to Saudi Arabia's broader decarbonisation goals.

This particular ORC system marks a significant milestone as it is the first to recover heat from two separate kilns simultaneously. It showcases the exceptional flexibility of Turboden's ORC technology, which is designed to operate efficiently even when one of the kilns is offline for maintenance. This ensures continuous energy generation and maximises the utilisation of available waste heat.

Moreover, the project demonstrates the strategic advantage of deploying a high-efficiency, large-scale ORC system, which benefits from a lower EUR/kW investment cost compared to smaller, low-temperature modular units. These smaller systems typically achieve less than half the efficiency and offer limited additional flexibility, making them less suitable and attractive for larger cement plants.

While a variety of strategies, including the use of lower-carbon fuels, improved material efficiency and carbon capture technologies, are essential to reducing emissions in line with global climate targets, WHP stands out as one of the most immediate and cost-effective solutions to enhance both the sustainability and profitability of cement plants.

Operational flexibility: enabling carbon capture

Compared to traditional waste heat to powersystems such as SRC, ORC technology offers clear advantages for cement producers. One of its most significant strengths is operational flexibility: ORC systems can efficiently manage thermal input variations from 20 to 110 per cent of the design load, while maintaining efficiency levels close to the nominal one.

This flexibility is particularly valuable for plants integrating carbon capture solutions, such as oxy-fuel combustion or post-combustion capture, where process conditions may evolve over time. ORC turbines maintain high efficiency both before and after kiln line modifications.

Turboden is already pioneering this approach with a 7.5MW ORC unit for Holcim's Go4Zero project in Belgium, a flagship initiative in the context of carbon capture and storage (CCS).

Turboden ORC systems are fully automated, eliminating the need for constant on-site supervision and allowing cement plant teams to focus on their core operations.

The WHP plant is installed in bypass to the existing gas treatment line, ensuring that clinker production remains uninterrupted even during ORC maintenance or downtime.

Unlike solar PV or other renewable options, WHP offers superior economic efficiency thanks to its high utilisation rate; it can operate continuously whenever the cement plant is running, delivering significantly more annual power while requiring minimal space.

Recent years have shown how energy price fluctuations can impact competitiveness, even in strong markets. WHP with ORC is now a mature, proven solution that locks in a stable electricity cost for the entire plant life cycle, reducing exposure to sudden price spikes.

Conclusion

With electricity and gas prices remaining unpredictable, the introduction of escalating carbon taxes on CO_2 emissions (a trend already widespread in many regions) combined with incentives for industrial decarbonisation, the traditional cost barrier that once hindered energy efficiency investments in cement plants is getting thinner and thinner.

The global drive towards sustainability might soon remove this barrier entirely, pushing cement producers to prioritise smart, effective solutions that enhance operational efficiency and reduce emissions.

Backed by over four decades of experience and offering the flexibility to deliver electricity or high-temperature heat based on project needs, Turboden is ready to lead this transition, supporting the cement industry on its path to a more sustainable future. ■