Unlocking Sustainable Energy Solutions

Mirko Ferrari, Turboden, examines the role of ORC-based waste heat recovery in improving energy efficiency and reducing CO_2 emissions.

The cement industry faces a pressing challenge: meeting growing demand while drastically reducing CO_2 emissions. Although almost 140 countries have committed to net zero targets, the CO_2 intensity of cement production has remained largely unchanged in recent years. Achieving the emission reductions required in Europe by 2030 will therefore demand immediate and tangible improvements in plant efficiency.

Among the most effective levers available today, waste heat-to-power (WHP) stands out as a proven and effective solution. During clinker production, large quantities of high-temperature exhaust gases are released. Without recovery systems, this energy is completely wasted, and additional resources such as water and electricity must be consumed for cooling. By installing organic Rankine cycle (ORC)-based WHP systems, cement plants can transform this untapped thermal energy into clean electricity, typically covering up to 30% of a plant's power demand. The result is a direct reduction of scope 2 emissions, improved operational efficiency, and long-term cost savings.

The recent introduction of the EU's Carbon Border Adjustment Mechanism (CBAM) adds an additional layer of urgency, this time for non-EU producers. CBAM ensures that imported cement bears the same carbon cost as EU-produced materials. While the transitional phase (2023 – 2025) focused on emissions reporting, from 2026 importers must purchase and surrender CBAM certificates based on the embedded CO_2 of their products. This mechanism reinforces the economic value of energy-efficiency investments. As electricity-related emissions become increasingly scrutinised, technologies that reduce scope 2 CO_2, such as ORC-based WHP, help lower the carbon intensity of cement production, mitigating the impacts of CBAM.

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

ORC deployment in cement plants

Turboden offers ORC solutions ranging from 600 kW to 40 MW 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 heat recovery systems.

Between 2024 and 2025, Turboden secured six new projects within the cement industry, representing a combined installed capacity of over 35 MW of clean electricity. This achievement highlights the growing appeal of WHR 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 six ORC plants in the cement sector, further reinforcing its leadership in industrial energy efficiency.

A standout example is the 13 MW ORC plant delivered to the Riyad Cement Company in the Kingdom of Saudi Arabia. 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 like ORC particularly advantageous.

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

This particular ORC system marks a significant milestone as 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 capability ensures continuous energy production 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 €/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 less attractive for larger cement plants.

Operational and economic benefits of ORC-based WHR

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. By capturing and utilising waste heat to generate electricity, cement plants can enjoy several benefits.

Improved 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 grids (or produce with alternative methods such as ICEs) for the production plant operations, thus lowering energy bills. Additionally, cement plants that 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, WHP levelised cost of energy (LCOE) is typically lower compared to other renewable energy sources like 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 last point is particularly relevant in countries where water scarcity is a real problem that needs to be addressed.

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 decreased global carbon emissions.

Enhancing competitiveness

Cement plants that prioritise sustainability and energy efficiency are better positioned to compete in a market more and more focused 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

The cement industry is responsible for approximately 7% of global CO_2 emissions, according to the IEA. By reducing energy consumption and carbon emissions through ORC technology, cement plants can contribute to global efforts to mitigate climate change and minimise their impact on the environment.

ORC system configuration and operating principles in cement plants

Cement plants typically have two sources of recoverable thermal power that can be utilised through an ORC unit: exhaust gas from the preheater towers and hot air from the clinker cooler. Turboden has installed numerous ORC units in cement plants, recovering energy from either or both sources. The electric power output of these units ranges from 1 MWe to 13 MWe, depending on the exploitable thermal source conditions. However, Turboden can offer units with mechanical power ranging from 600 kWe up to 40 MWe from a single turbine, and it has successfully implemented more than 460 ORCs worldwide in different applications.

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 pollutants 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, a core product of Turboden, generating mechanical power, which is converted into electric power by a connected generator. The expanded vapour then passes through an internal heat exchanger, called a regenerator, where it releases heat to its liquid phase coming from the opposite side. After the regenerator, the vapour enters the condenser, where it 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.

Compared to traditional heat recovery systems like 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% of the design load, while maintaining efficiency levels close to nominal one. This flexibility is particularly valuable for plants integrating carbon capture solutions, such as oxy-fuel combustion with post-combustion capture, where process conditions may evolve over time. ORC turbines maintain high efficiency both before and after kiln line modifications.

Case study

Turboden is already pioneering this approach with a 7.5 MW ORC unit for Holcim's Go4Zero project in Belgium, a flagship initiative in the context of CCS. There have been several benefits, including:

- 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 kWh/y 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 lifecycle, reducing exposure to sudden and unpredictable price spikes. Existing Turboden installations have already demonstrated this resilience in real-world conditions.

Conclusion

With energy prices remaining unpredictable, and the introduction of escalating carbon taxes on CO_2 emissions 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 toward sustainability might soon remove this barrier entirely, pushing cement producers to prioritise smart, effective solutions that enhance operational efficiency and reduce emissions. ■