WHR: unlocking sustainable energy for cement plants

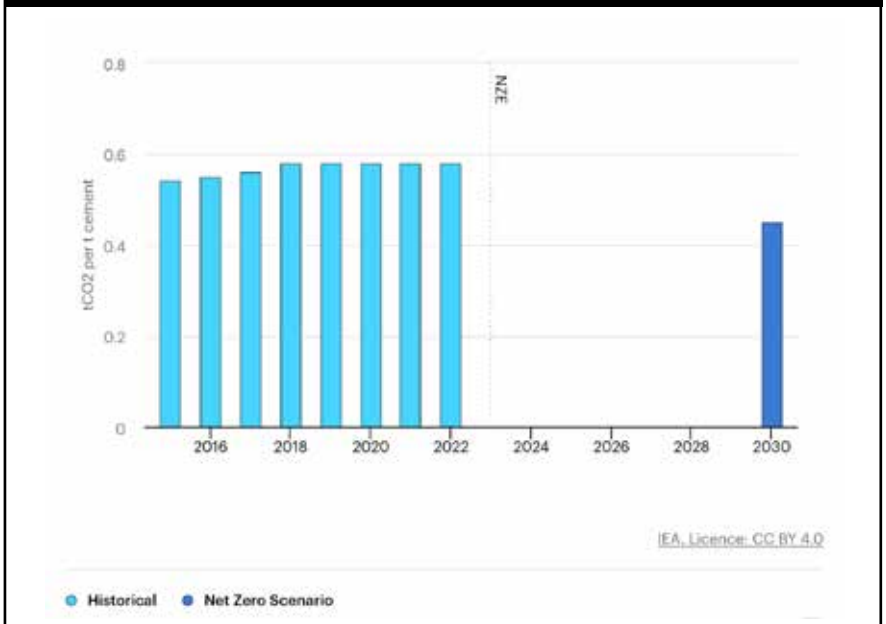
The global cement sector is currently facing one of its most formidable sustainability challenges: it must continue to satisfy the ever-increasing worldwide demand for cement while reducing the CO_2 emissions from its production process. Waste heat recovery (WHR) is one strategy to reduce fossil fuel consumption, and therefore, CO_2 emissions.

■ *by **Turboden SpA**, Italy*

As of the outset of 2024, approximately 145 countries worldwide have either declared or are contemplating net-zero targets. Notably, for European nations, this endeavour is commonly referred to as achieving net-zero status by 2050.

Nevertheless, based on the findings of the International Energy Agency (IEA), the direct CO_2 intensity of cement production, measured in tons of CO_2 emitted/t of cement produced, has remained largely unchanged over the past five years (see Figure 1). This stands in stark contrast to the required annual reduction of four per cent leading up to 2030, as outlined in the pathway to align with the Net Zero Emissions (NZE) by 2050 Scenario.

Figure 1: direct emissions intensity of cement production



Source: https://www.iea.org/energy-system/industry/cement

Reducing fuel consumption and CO_2 emissions in the cement industry

Given this context, improving the energy efficiency of cement plants emerges as one of the most rapid and impactful strategies to curtail global fuel consumption and subsequently reduce Scope 2 CO_2 emissions (indirect emissions). It follows logically that implementing waste heat recovery (WHR) represents the most direct approach to bolstering the energy efficiency of the clinker production process, as it has the potential to generate up to 30 per cent of the electricity utilised by the cement plant. This is achieved by capturing the thermal energy present in the hot gaseous streams generated during the clinker production process. Failing to employ such measures not only results in the wastage of this energy but also requires the consumption of valuable resources, such as water or electricity, for the processing and cooling of these streams.

In the past 15 years, the cement industry has seen organic Rankine cycle (ORC) technology emerging as a reliable and viable alternative to the conventional steam Rankine cycle (SRC). This shift has been driven by ongoing advancements in technical solutions, improved economic competitiveness and a heightened global emphasis on achieving greener and more sustainable practices. Therefore, heat recovery via ORC has become progressively appealing within the industry.

Process description

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.

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, Turboden's core product, 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 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.

WHR benefits

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

- **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 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, WHR levelised cost of energy (LCOE) is typically lower compared to 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 last point is particularly relevant in countries where water scarcity is a real problem that needs to be addressed.
- **Enhanced competitiveness** – cement plants that prioritise sustainability and energy efficiency are better positioned to compete in a market more and more 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** – the cement industry is responsible for approximately seven per cent 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.
- **Reduced fossil fuel consumption** – the electricity produced by the ORC unit is used to feed part of the cement plant 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.
- **Adaptability in view of carbon capture systems** – ORC technology exhibits flexibility during operation, as it can handle thermal power inputs ranging between 20-110 per cent of the design inlet, while maintaining high efficiency close to the design level. Due to this adaptability, ORC turbines remain a viable option for cement plants considering the integration of carbon capture technologies such as oxyfuel, or other exothermic processes,

Turboden high-efficiency axial turbine

and post-combustion capture. These turbines can operate at high efficiency both before and after the modification of the kiln line.

• **Reduced personnel requirements** – ORC systems operate automatically, eliminating the need for a continuing personnel presence at the plant, allowing cement plant operators to focus on their core business.

Increasing application of WHR in the cement industry

Turboden, part of Mitsubishi Heavy Industry and the foremost global supplier of ORC plants designed for medium-to-high-temperature applications in energy-intensive sectors, has installed numerous ORC units in cement plants, recovering energy from either or both sources. The electric power output of these units ranges between 1-13MWe, depending on the exploitable thermal source conditions. However, Turboden can offer units with mechanical power ranging from 600kWe up to 20MWe from a single turbine and it has successfully implemented more than 450 ORCs worldwide in different sectors.

Throughout 2022-23, Turboden effectively secured seven new projects in the cement industry. These projects collectively boast an overall rated capacity exceeding 60MW of clean energy. This achievement underscores the increasing allure of WHR via ORC technology for cement plants.

The recently secured project for a 13MW ORC plant in Saudi Arabia serves as a prime example of how Turboden ORC technology can compete in size ranges traditionally dominated by SRC systems. This is particularly significant in regions where water scarcity renders it imperative to avoid wastage, highlighting ORC technology's adaptability and efficiency even in such challenging environments.

This plant, recovering the heat from the preheater and clinker cooler gases of the 5000tpd clinker production lines, is expected to produce more than 80GWh per annum of clean electricity. This will result in a decrease of over 45,000tpa of CO_2 emissions, thereby contributing to the overall reduction of greenhouse gas emissions in the country.

While numerous strategies can and should be employed to decrease carbon emissions from cement plants in alignment with environmental targets, including transitioning to lower-carbon fuels, enhancing material efficiency, and adopting carbon capture technologies, WHR from the production process represents an effective and efficient method for promptly enhancing the sustainability and financial viability of cement plants. Integrating WHR with other technologies will be pivotal for ensuring the viability and sustainability of cement plants in the future.

In pursuit of affordable decarbonisation technologies

Due to electricity and gas price uncertainty, coupled with the imposition of escalating carbon taxes on CO_2 emissions, a trend already prevalent in many countries, and the availability of incentives aimed at industrial decarbonisation, the longstanding cost barrier that once impeded investments in energy efficiency interventions within cement plants is steadily eroding. Furthermore, the global pursuit of a more sustainable world is poised to dismantle this barrier entirely, encouraging more cement plants to prioritise investments in intelligent and effective solutions to enhance their efficiency.

Leveraging over a decade of industry expertise and offering the versatility to generate either electricity or high-temperature heat based on project specifications, Turboden stands ready to embrace this challenge and lead the sector toward a more sustainable future. ■

The 14MW WHR-based power plant installed by Turboden reduces this plant's carbon footprint