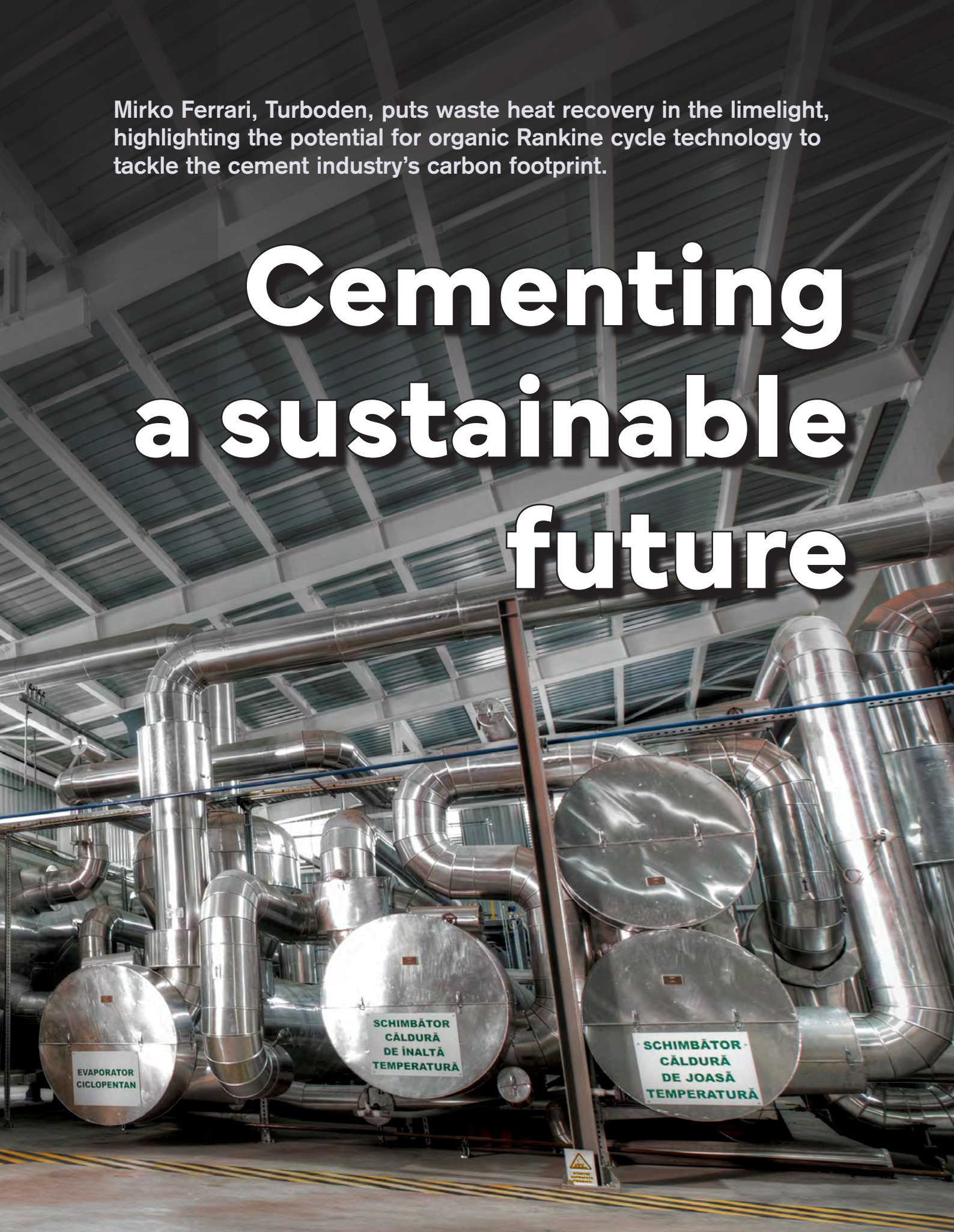
Over the last decade, the cement industry has witnessed the emergence of organic Rankine cycle (ORC) technology as a viable and secure alternative to the traditional steam Rankine cycle (SRC). The continuous improvement in technical solutions, enhanced economic competitiveness, and the growing global focus on building a greener and more sustainable environment have made heat recovery through ORC increasingly attractive. Governments around the world have also played a significant role in driving this shift towards sustainable practices.

To tackle cement emissions, various jurisdictions such as the European Union (including the European Free Trade Association), Canada, and Korea have implemented pricing schemes. China, which accounted for a significant majority (~55% according to the International Energy Agency [IEA]) of global cement production in 2021, has also recently announced its intention to introduce a pricing mechanism for cement emissions, potentially as early as 2023.

In 2022 Turboden, a provider of ORC solutions for medium/high temperature applications in energy-intensive industries, secured four new projects in the cement industry and some others will be finalised

Mirko Ferrari, Turboden, puts waste heat recovery in the limelight, highlighting the potential for organic Rankine cycle technology to tackle the cement industry's carbon footprint.

Cementing a sustainable future



during this year. This achievement underscores the increasing appeal of waste heat recovery using ORC technology.

According to the International Energy Agency, the direct CO_2 intensity of cement production (measured in tons of CO_2 per ton of cement produced) has been rising at a rate of approximately 1.5% per year between 2015 and 2021. This is in contrast to the necessary annual decline of 3% until 2030, as outlined in the Net Zero Emissions by 2050 Scenario.

While various strategies can be implemented to reduce carbon emissions in cement plants, such as carbon capture technologies, transitioning to lower-carbon fuels, and promoting material efficiency, waste heat recovery (WHR) from the production process stands out as one of the most effective and efficient ways to immediately make cement plants more sustainable and financially rewarding. A WHR plant can generate up to 30% of the electrical energy consumed by a cement plant. Combining WHR with other technologies will be crucial for the cement plants of the future.

Cement plants are known for consuming a significant amount of energy in heating and grinding raw materials. These processes result in substantial waste heat as a byproduct. By capturing and utilising this waste heat to generate electricity or both electricity and thermal power in the form of hot water (up to 110˚C), cement plants can enjoy several benefits, including:

- 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 for 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, mitigating any risks associated with energy market fluctuations. Moreover, WHR's Levelised Cost Of Energy (LCOE) is typically lower compared to other renewable energy sources like solar or wind. By using an ORC unit, cement plants can also cool down the gas produced while generating electrical 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.

- Enhancing competitiveness: with the increasing focus on sustainability and energy efficiency, cement plants that demonstrate their commitment to reducing their carbon footprint will be better positioned in the market.

- 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.

Figure 1. Carpatcement plant.

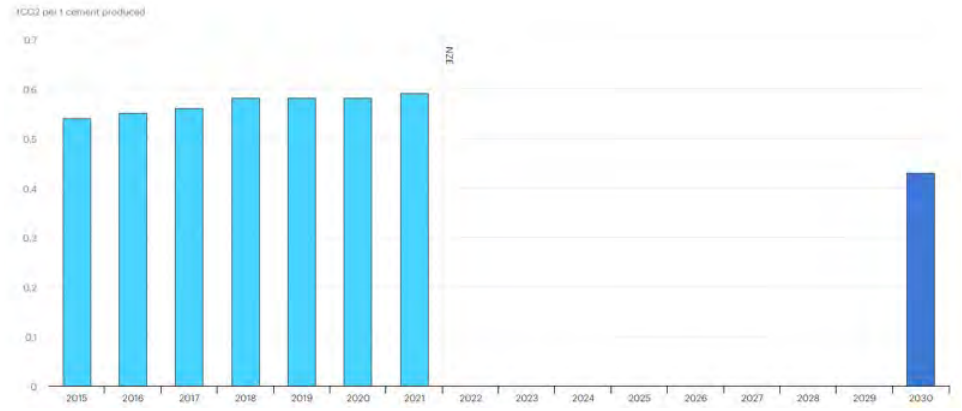


Figure 2. Carbon intensity of cement production.

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- Reducing fossil fuel consumption: in cement facilities with power plants, the electricity produced by the ORC unit is used to power 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.

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 electrical power output of these units ranges from 1 – 11 MWe, depending on the exploitable thermal source conditions. However, Turboden can offer units with mechanical power ranging from 600 kWe up to 20 MWe from a single turbine.

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

Table 1. Turboden references in cement plants.

Plant	Country	Start up	Kiln capacity (tpd)	Heat source	Heat carrier	ORC gross electric power (kW)
CIMENTS DU MAROC (HeidelbergCement Group)	Morocco	2010	5000	PH	thermal oil	2000
HOLCIM ROMANIA (LafargeHolcim Group	Romania	2012	4000	PH + CC	thermal oil + superheated water	4000
CRH SLOVAKIA (former Holcim Group)	Slovakia	2014	3600	PH + CC	thermal oil	5000
CARPATCEMENT (HeidelbergCement Group)	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	1500
ÇİMKO (Sanko Group) - EPC: CTP Team	Turkey	2019	9500	CC	thermal oil	7000
HOLCIM SUISSE ECLÉPENS (LafargeHolcim Group)	Switzerland	2020	2300	PH + CC	thermal oil	1300
SÖNMEZ ÇIMENTO EPC: CTP Team	Turkey	2020	6000	PH + CC	thermal oil	8100
SECIL EPC: CTP Team	Portugal	Under construction	3800	PH + CC	thermal oil	7000
CIMPOR (SOUSELAS) EPC: CTP Team	Portugal	Under construction	4200	PH + CC	thermal oil	8400
CIMPOR (ALHANDRA) EPC: CTP Team	Portugal	Under construction	3100	PH + CC	thermal oil	6200
UNDISCLOSED (undisclosed)	UAE	Under construction	7500	PH + CC	thermal oil	10 000
MEDCEM EPC: CTP Team e CTN Makina	Turkey	Under construction	10 000	CC	thermal oil	11 000

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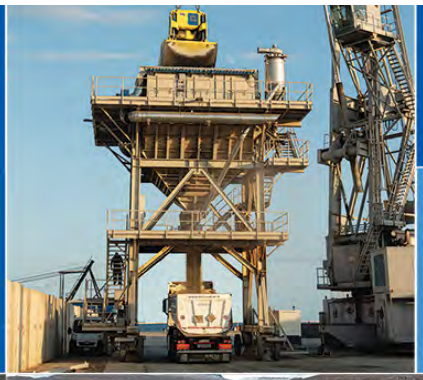

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handle the gas stream's specific conditions, managing pollutants and dust commonly present in the gas. The thermal vector then transfers the thermal power to the ORC working fluid, often cyclopentane for cement plant applications (being the working fluid that best fits with the thermal source characteristics in terms of temperature). The cyclopentane is evaporated and enters the turbine (Turboden's core product), generating the required mechanical power, which is converted into electrical 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 continuously pumped back through the regenerator to the evaporator, completing its cycle.

Compared to other heat recovery solutions like the traditional steam Rankine cycle, ORC technology possesses several advantages. It exhibits flexibility during operation, as it can handle thermal power inputs ranging from 10 – 110% of the design inlet, while maintaining efficiency close to the design level. Additionally, ORC systems operate automatically, eliminating the need for constant personnel presence at the plant, allowing cement plant operators to focus on their core business. All these reasons, in addition to others, pushed the owner of the Medcem plant to select the Turboden technology for its second clinker production line. This decision was made despite the fact that the other line in the same plant is already equipped with an SRC turbine.

The waste heat recovery system is installed in bypass to the existing gas treatment line, ensuring uninterrupted clinker production even if the waste heat recovery unit experiences downtime. Furthermore, when compared to other green energy technologies like solar photovoltaic (PV), WHR has a higher economic efficiency due to its higher utilisation rates (it can ideally operate throughout the cement plant's operating time, resulting in higher kWh production annually) and requires less space.

In recent years, the volatility of energy costs has demonstrated their ability to impact businesses, even in growing markets. WHR with ORC has evolved into a mature and proven technology that can secure a fixed electricity price for the plant's entire lifespan. This protects cement plants, as observed in previous years with existing Turboden ORC installations, from sudden and unpredictable peaks and fluctuations in energy prices.

Since joining the Mitsubishi Heavy Industries group in 2013, Turboden has brought over 40 years of ORC unit design expertise to the table.

The company now benefits from the strong financial and technical support of its parent company, providing robust guarantees to its clients.

In addition, as Turboden is part of a Japanese company, it can take advantage of the Joint Crediting Mechanism (JCM). The JCM provides opportunities for Turboden to access and benefit from the incentives and support offered by the Japanese government for projects related to emissions reduction and sustainable development in partner countries (as of April 2023, 26 countries have been involved in this mechanism).

Conclusion

With electricity prices on the rise in many countries, unlikely to return to pre-pandemic levels due to the adoption of greener yet costlier electricity generation technologies, the imposition of increasing carbon taxes on CO_2 emissions (already implemented in many countries), and the availability of incentives aimed at industrial decarbonisation, the historical cost barrier that hindered investments in heat recovery for cement plants via ORC technology is becoming increasingly fragile. The pursuit of a more sustainable world will ultimately break down this barrier, compelling more cement plants to invest in intelligent and effective solutions to enhance their efficiency. With over a decade of experience in the industry, Turboden is prepared to take on this challenge and lead the sector towards a greener future. ■

About the author

Mirko Ferrari is an Energy Engineer who graduated from Politecnico di Milano, holding a Master's degree in Renewable Energy and Environmental Sustainability.

Mirko has worked at Turboden since 2020 and is a Sales Engineer for Industrial Heat Recovery with a particular focus on energy intensive industries such as cement, glass, and steel production processes.

He supports potential customers to find the optimised configuration for each project with a consistent attitude to deliver high value customised solutions supported by a solid academic background.