Value from waste heat

Waste heat recovery represents a significant opportunity for cement producers to improve plant efficiency and reduce their carbon footprint. This article looks at several proven technologies for capturing and utilising waste heat, and explores additional pathways for industry decarbonisation through sector coupling.

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In 2021, the Global Cement and Concrete Association (GCCA), whose members comprise 80 per cent of the global cement industry outside of China, published a formal roadmap for achieving net zero carbon emissions by 2050. The roadmap establishes an intermediate target of cutting greenhouse gas (GHG) emissions by 25 per cent by 2030.[1]

Achieving this goal will require aggressive action from producers in the next 2-3 years. The cement industry is the third-largest industrial energy consumer and accounts for around 25 per cent of industrial CO_2 emissions globally.[2] Only the steel industry has a higher carbon footprint.

Burning fuel for heat used in the preheater and kiln is the single largest source of energy consumption and associated emissions in cement manufacturing. By some estimates, as much as 40-45 per cent of the heat input into the preheater and kiln is lost/wasted via flue gases and surface dissipation.[3]

Capturing this thermal energy and using it to produce power is one of many proven ways to achieve incremental emissions reductions while at the same time reducing electricity costs. In some instances, it may

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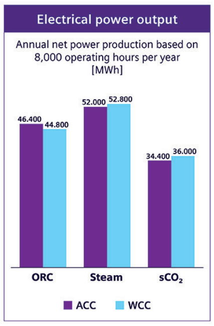
Figure 1: steam cycle outperforms ORC and sCO_2 in terms of net power output

	Unit	ORC WHR		Steam WHR		sCO_2 WHR	
Performance @ Design conditions							
Type of cooling	-	ACC	WCC	ACC	WCC	ACC	WCC
Heat recovered (PH & CC)	MW_{th}	25.7	25.6	28.8	29.0	28.6	28.6
Gross power output	MW_e	6.4	6.3	7.0	7.3	8.2	8.3
Efficiency gross	-	**24.8%**	**24.5%**	**24.2%**	**25.0%**	**28.7%**	**29.0%**
Auxiliary power consumption	MW_e	0.6	0.7	0.5	0.7	3.9	3.8
Net power output	MW_e	5.8	5.6	6.5	6.6	4.3	4.5
Efficiency net	-	**22.5%**	**21.8%**	**22.4%**	**22.7%**	**15.0%**	**15.7%**

Ambient design conditions
- Temperature: 20°C
- Pressure: 1.018 bara
- Relative humidity: 74%

WHRU PH design conditions
- Mass flow: 73.4 kg/s
- WHRU inlet temperature: 330°C
- WHRU outlet temperature: 195°C

WHRU CC design conditions
- Mass flow: 70.4 kg/s
- WHRU inlet temperature: 350°C
- WHRU outlet temperature: down to min.



also be possible to export heat and/or excess power outside the plant, creating possibilities for new revenue streams and carbon offsets.

Generating power from steam turbines

The most widely-accepted waste heat recovery (WHR) method in cement plants today is to capture and combust flue and waste gas streams from the preheater and clinker cooler.

Siemens Energy has conducted several studies for cement producers in recent years to determine the most efficient way of generating power from WHR. This includes evaluating power cycles that use superheated steam, organic fluids (organic Rankine cycle) and supercritical CO_2 (sCO_2). The studies have shown that, in most cases, a traditional steam cycle outperforms alternative technologies in terms of net electrical power output for both air-cooled (ACC) and water-cooled (WCC) applications (see Figure 1).

Several factors will determine the amount of steam and power that can be produced from the waste heat, including the waste gas temperature and composition, kiln design and capacity, and raw material moisture content.

The Rohrdorf cement works in Germany

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commissioned the first waste heat and gas power plant in Europe in 2012. At the outset, the plant produced one-third of the site's power while saving 12,000tpa of fossil fuels and reducing CO_2 emissions by 30,000tpa.[4,5]

Other cement waste heat power plants have seen average power increases of 15-20 per cent. This can equate to significant cost savings in the form of reduced electricity bills for grid-connected plants, particularly for regions with highly variable prices.

The extent of carbon abatement ultimately depends on the source of upstream power generation. Significant CO_2 reductions are possible if the primary feedstock for the grid power plant is

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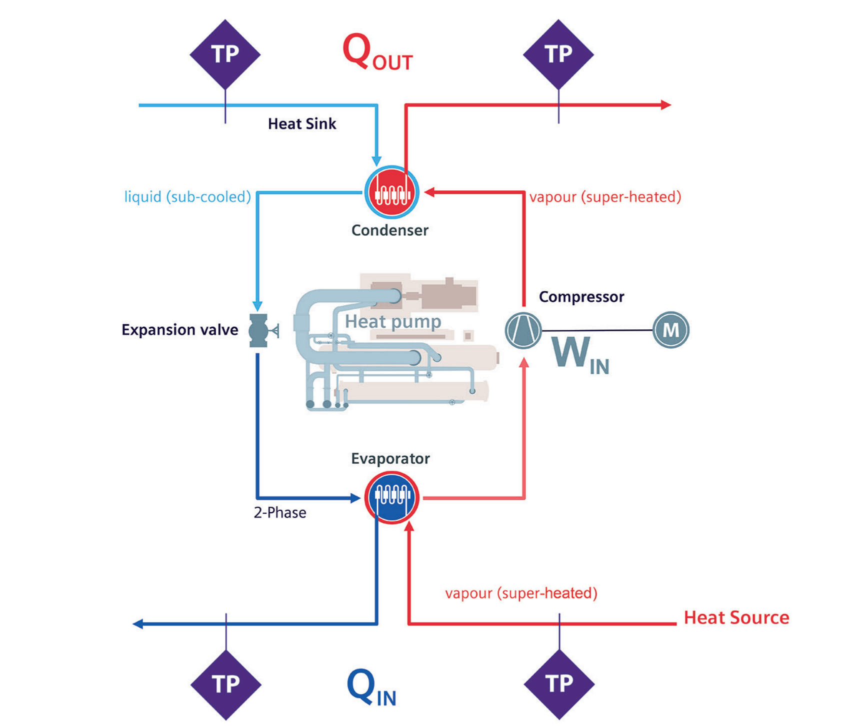
coal. In real-world applications, plants employing waste heat recovery systems have reduced carbon intensity by as much as 25kg/t of clinker produced.

Additional heat can be recovered from the hot exhaust streams via a heat recovery steam generator (HRSG) for sites that utilise on-site power generation with gas turbines. As there are several different types of HRSGs available (drum-type, once-through, etc), working closely with original equipment manufacturers (OEMs) to determine the optimal configuration is critical. The design of the steam cycle and optimal sizing of the steam turbine are also important to ensure maximum power output, given the available thermal energy.

High-temperature heat pumps

Industrial heat pumps have recently gained traction in other carbon-intensive sectors, including chemical and refining applications. While they have not been widely used for WHR in cement production, this will likely change as the industry seeks

Figure 2: simplified diagram of high-temperature heat pump



additional decarbonisation pathways.

Heat pumps operate on a vapour-compression cycle where the heat of compression is leveraged to raise low-grade heat to useful temperatures. So, naturally, heat flows from a higher to a lower temperature level. Heat pumps, however, can force the heat flow in the other direction, using a counterclockwise Carnot cycle process.

A relatively small amount of drive energy is required to run the process. As the lower temperature heat is normally a heat sink of otherwise unused waste heat, the drive energy is the sole energy input for the heat pump. In modern designs, the usable thermal heat energy received from a heat pump exceeds the drive

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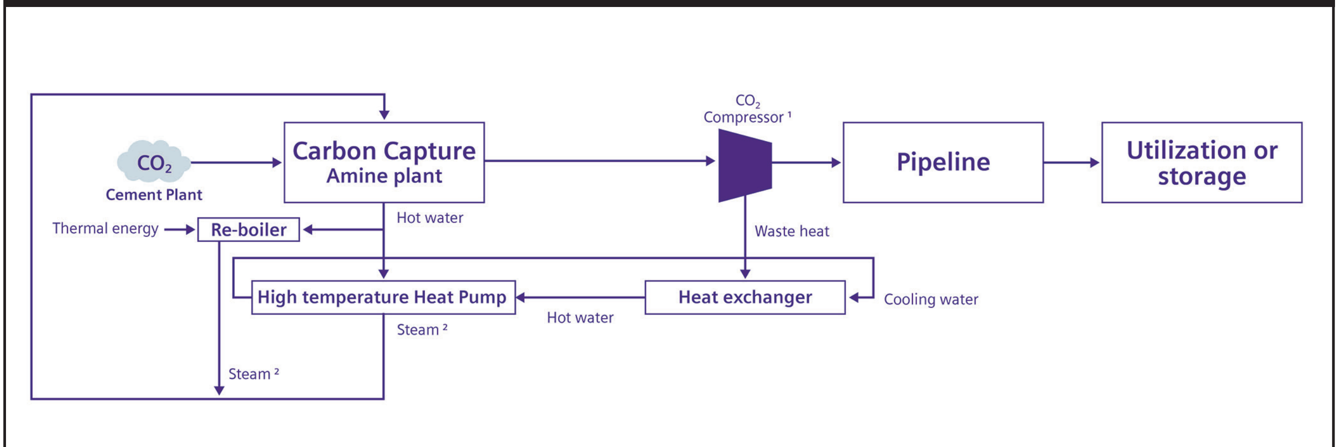
energy by a factor of 3-6. In simple terms, this means 3-6 times more heat energy is provided to the heat sink than the amount of electricity consumed. Although this may sound impossible, it is important to understand that there is no violation of thermodynamics associated with heat pumps. The units themselves do not create

Figure 3: schematic of a heat pump in combination with amine-based post-combustion carbon capture



"Electrolysers use renewable energy from wind, solar or hydro to split water into oxygen and hydrogen. The green hydrogen can then be compressed and used as a zero-emissions fuel in the kiln and calciner."

heat but rather move it from a region of lower temperature to one of higher temperature.

Modern, low-temperature heat pumps can achieve temperature levels of up to 100˚C. In recent years, Siemens Energy has been involved in demonstration projects where temperatures up to 150˚C and a pressure level of 4bar were achieved using modern high-temperature heat pumps. Further progress has been made to extend this range up to 270˚C and pressure levels up to 60bar using subsequent steam compression. Such configurations recently became bid-ready in the marketplace.[6]

There are several ways heat pumps can be applied to accelerate the decarbonisation of cement production – both as a standalone solution and in combination with traditional waste heat recovery systems. One way is through integration with post-combustion carbon capture systems.

For plants near municipalities, there is also the potential to export heat or steam for district heating purposes. In Europe, there are now multiple chemical complexes where heat pumps are used for this purpose.

Carbon capture and oxy-fuel combustion

Most carbon capture systems, including amine-based solutions, require heat/steam to release CO_2 once it has been absorbed by the amine. The solvent then has to be cooled for adsorption so it can be regenerated and recycled. While the low-pressure steam generated from combusting flue and waste gases can be sufficient to meet the capture system's heat demands, it will reduce the amount of available steam for power generation.

Heat pumps can be installed to capture the thermal energy from solvent adsorption, as well as from the CO_2 compressor or the exhaust of gas turbines. Doing so can improve the carbon capture system's overall efficiency and maximise the steam turbine's net power output.

For certain plants, further efficiency increases may be possible with oxy-fuel combustion. In such cases, nitrogen and oxygen are separated from ambient air using an air separation unit (ASU). Adding pure oxygen to the kiln fuel creates a high-concentration CO_2 flue gas that is easier to process and utilise in applications downstream.

Generally speaking, there are two options for oxy-fuel combustion: full-scale (ie, pyroprocess) and partial-scale. Full-scale processes exhibit extremely high capture rates (up to 99 per cent). However, they typically require some modifications to the cement production process. Partial-scale combustion displays lower capture rates (55-75 per cent) but is often more economical and has a lower capital expenditure requirements.

Electrolysis plants

Another potential decarbonisation pathway cement producers have considered in recent years is integration with an electrolysis plant.

Electrolysers use renewable energy from wind, solar or hydro to split water into oxygen and hydrogen. The green hydrogen can then be compressed and used as a zero-emissions fuel in the kiln and calciner. For each kilogram of hydrogen, 8kg of oxygen is also produced. While this would typically be vented, it could be used for oxyfuel combustion.

Modern electrolysers demonstrate high efficiency even under partial loads. For example, a 100MW electrolysis plant can produce ~2tph of H_2 and ~16tph of O_2 saturated with water.

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If green hydrogen cannot be combusted onsite, it could be stored or sold into the downstream refining market to produce synthetic fuels. If a carbon capture system is installed, there is also potential to combine the green hydrogen with CO_2 to form eMethanol. The eMethanol can be sold and exported to decarbonise mobility and/or marine transport applications or potentially used as a fuel onsite.

The road ahead

Cement production accounts for an estimated eight per cent of global CO_2 emissions. While the industry is making progress in reducing its carbon footprint, more aggressive action will be required to meet intermediate emissions targets and drive a successful energy transition.

Waste heat recovery systems are one of several established technologies that can be leveraged to achieve incremental emissions reductions cost-effectively. Using these systems in combination with other technologies (eg, carbon capture, electrolysers, etc) represents a powerful decarbonisation pathway that can put the cement industry on track to reach net zero by 2050. ■

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