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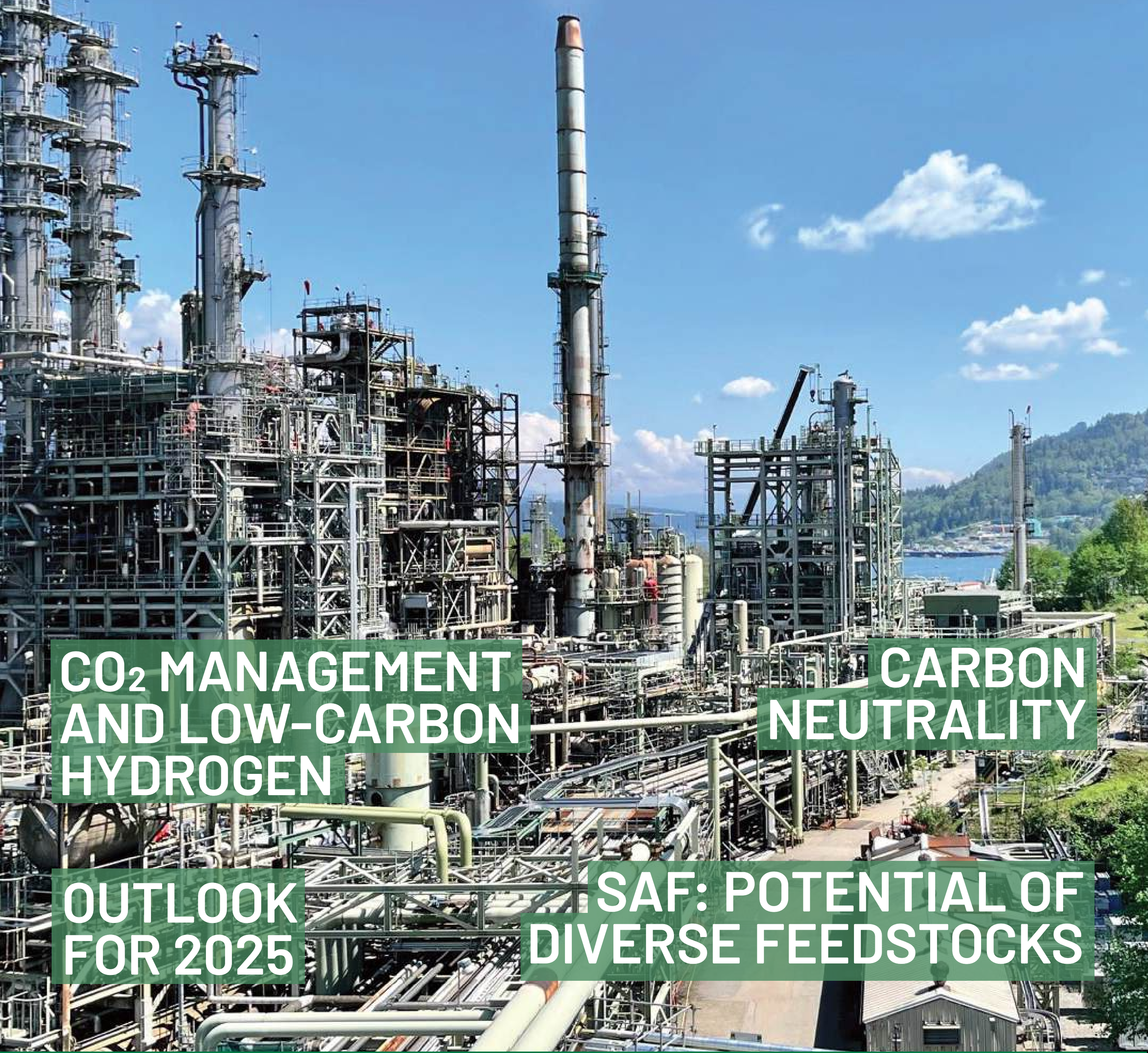

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Unlocking the potential of waste heat recovery

Boosting efficiency and sustainability with waste heat recovery systems in the chemical industry

Sara Milanesi
Exergy International

Decarbonising chemical processes, much like other energy-intensive processes, is essential to achieve net zero by 2050 *(IEA, 2023)*. In fact, the chemical sector accounts for approximately 14.5% of all industrial CO_2 emissions (1,342 Mt from a total of 9,316 Mt) and ranks as the largest industrial energy consumer *(IEA, 2022)*.

Global demand for chemical products is expected to grow by around 2.5 times by 2050, leading to a projected increase in both energy and non-energy uses of raw materials, heat, and electricity from 47.6 EJ to 88 EJ per year *(Perego & Ricci, 2023)*.

This scenario presents a unique challenge with respect to decarbonisation of the chemical industry as it is heavily reliant on fossil feedstocks (coal, crude oil, and natural gas) both as a source of energy and as raw materials.

Various technologies and measures can be deployed to reduce energy intensity and mitigate carbon emissions in the sector. These include the production and use of green hydrogen, carbon capture utilisation and storage (CCUS) solutions, circular reuse of plastic waste, replacement of fossil fuel raw materials with biomass, and improvements in energy efficiency for process heat.

Waste heat potential in the chemical industry

Among energy efficiency measures, the recovery of waste heat represents a viable

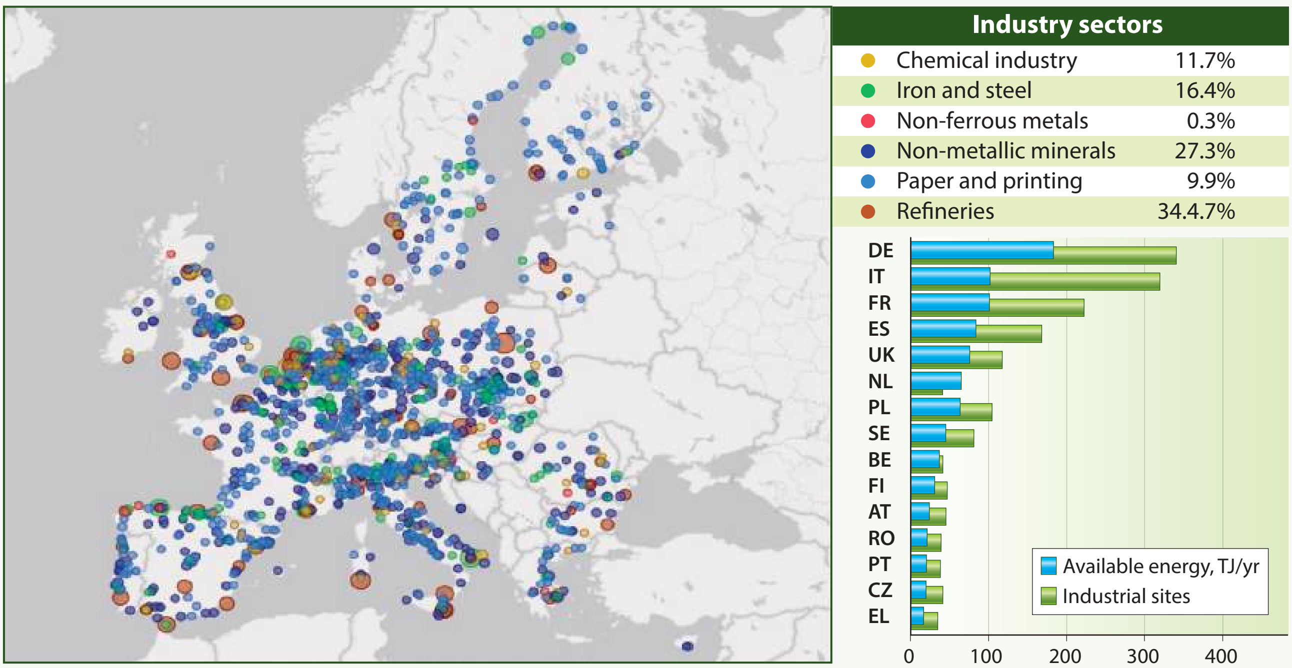

Figure 1 Map of industrial sites with significant waste heat recovery potential in Europe

Country	Clinker	Container glass	Flat glass	Paper	Primary steel	Second steel	Chemicals	Food and beverages	Refinery	Total
Belgium	33.4	0	12.1	8.1	14.9	0.3	391.2	130.5	11.2	602
Denmark	9.5	0	0	1.9	0	0	26.1	54.5	2.6	95
France	85.5	36.9	12.1	32.5	32	0.7	453	427.3	20	1,100
Germany	164.2	47.3	19.2	89.4	89.8	1.6	1,367	486.4	32.6	2,298
Italy	98.6	41.3	12.1	34.3	19.7	2.2	357.4	266	23.3	855
Netherlands	13	0	0	11	20.6	0	666.8	193.5	19.8	925
UK	43.1	26.7	9.1	17.4	30.6	0.2	300.2	254.7	19.8	702
Total	**447.3**	**152.2**	**64.6**	**194.6**	**207.6**	**5**	**3,562**	**1,813**	**129.3**	**6,577**

Table 1 Estimated potential for installation of ORC power plants per selected country and per industrial sector (in MW electricity production)

and rapidly deployable solution that can optimise energy use and enhance the overall sustainability of chemical processes.

In one study, the Knowledge Center on Organic Rankine Cycle Technology (KCORC) identifies the waste recovery potential for 1,175 energy-intensive industrial sites across seven EU countries (see **Figure 1**) *(KCORC, 2022)*.

Estimates show that more than 50 MW of thermal energy is produced at each site, with 11.7% represented by the chemical industry. For waste heat sources above 250°C, considered more economically attractive, Organic Rankine Cycle (ORC) waste heat recovery plants could allow the installation of around 3.6 GW of electrical power in these industrial sites (see **Table 1**).

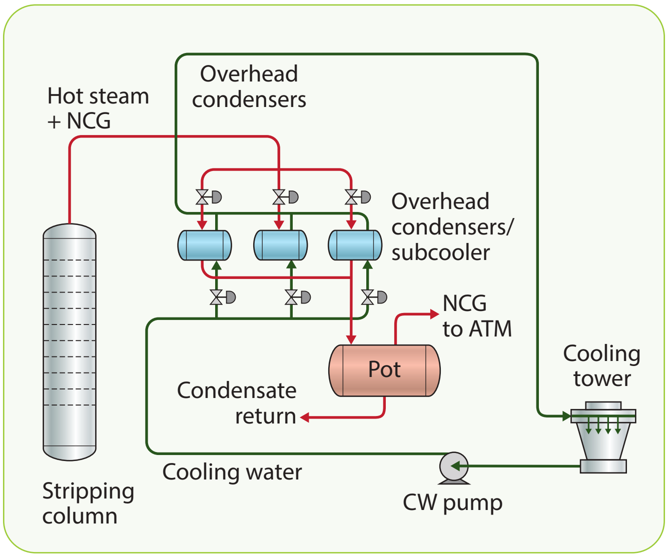

Figure 2 Traditional layout of chemical plant

Organic Rankine Cycle technology for waste heat recovery in the chemical sector

Exhaust heat is generated during various stages of chemical processes such as distillation, reaction processes, heat exchange and cooling systems, exhaust gases from combustion processes, and ventilation equipment.

This waste heat can be recovered and reused by employing different technologies depending on its characteristics and application.

One of the most efficient and economically viable technologies for waste heat recovery is the ORC, which operates effectively within a temperature range of 90°C to 400°C.

The ORC system is similar to the traditional Clausius-Rankine cycle, commonly used for electricity generation, but employs organic substances as the working fluid instead of water (steam). These substances have a lower boiling point and higher vapour pressure, making them more suitable for generating electricity from low-temperature heat sources. The organic fluid, which can be a hydrocarbon or a refrigerant, is selected based on its thermodynamic properties that best suit the available heat source. This allows for higher cycle and turbine efficiencies to be achieved.

The ORC operates as a closed thermodynamic cycle. Heat from a primary source warms and vaporises the organic fluid, which then expands through a turbine, producing mechanical energy that is converted into electricity. The fluid is then condensed and pressurised to restart the cycle.

Using an ORC cycle for waste heat recovery

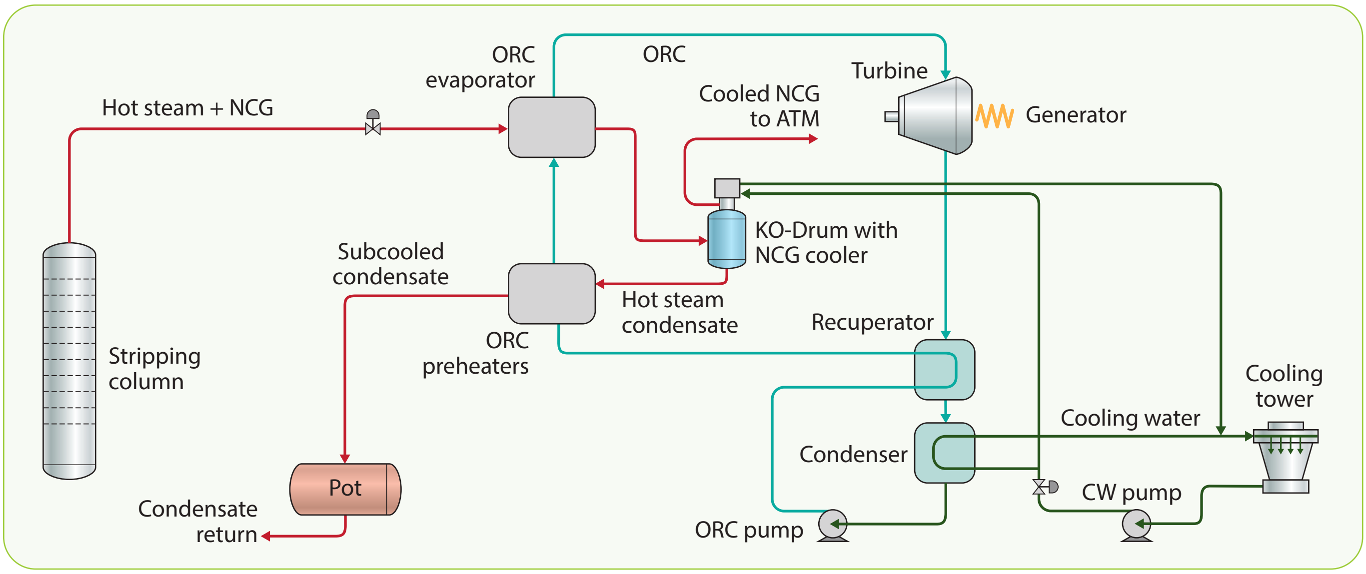

Figure 3 Layout with ORC WHR integration in the chemical process with overhead condensers

at low and medium-high temperatures or for small applications gives some advantages over a steam cycle, including:

- Higher efficiency and flexibility in operations, even at partial loads.
- Automated operations, which avoid dedicated trained personnel to run them.
- Low, easy maintenance and a long plant lifecycle.
- Enabling operation without water consumption by choosing an air-cooled condenser.

These characteristics make ORC technology a flexible, customisable solution suitable for retrofitting existing sites or greenfield installations.

In the chemical sector, ORC systems can recover waste heat from distillation processes by harnessing available heat from the overhead vapour of the distillation column and the non-condensable gas (NCG) stream from stripping columns. In these cases, the ORC system serves a dual function, providing significant benefits: it replaces the conventional condensers at the top of the column while simultaneously generating electrical energy (see **Figures 2** and **3**).

The process steam, NCG flow, and organic working fluid never come into contact, avoiding the potential issue of process steam and condensate contamination.

ORC waste heat recovery system with radial outflow turbine

Exergy International is a global provider of clean energy technologies and an expert in the design and supply of ORC systems. In 2009, the company introduced the Radial Outflow Turbine (ROT) for ORC systems (see **Figure 4**).

The unique configuration of Exergy's ROT allows for efficient conversion of thermal energy into mechanical power thanks to several technical features:

- Increased volumetric flow during expansion.
- Reduced leakage and rotor friction due to straight blades and radial design.
- Multiple inlets on the same rotor disk at different pressures.
- Up to nine stages on a single rotor disk, allowing for higher efficiency.
- Optimised pressure gradient distribution to limit vortex formation and fluid dynamic losses.
- Flexibility in choosing the cycle pressure with fewer technological limitations.
- Patented mechanical group, easily removable

Figure 4 Exergy's Radial Outflow Turbine

Figure 5 Overview of Exergy's ORC waste heat recovery installation at Sanfame's chemical plant

for quick and simple maintenance without fluid draining.

- Reduced rotation speeds, compatible with direct coupling to a generator.

Case study: Sanfame ORC waste heat recovery project

Jiangyin Xingjia New Material Co., part of the Sanfame Group, active in the chemical industry and polyester chemical fibre production, sought a low-carbon technology solution for a new greenfield polyethylene terephthalate (PET) manufacturing site of two production lines, each with a capacity of 750,000 tons per year.

Sanfame selected Exergy's ORC technology to achieve its sustainability goals. The plant comprises two ORC units, each rated at 2.9 MWe, for a total installed power of 5.8 MWe (see **Figure 5**). These units recover heat at 102°C from saturated polyester steam at the top of the stripping column and from the non-condensable gas (NCG) stream generated by the production process. This installation represents the highest power generation capacity ORC technology applied to the polyester industry.

The process steam flow and NCG are directed to the heat exchangers of the ORC system, which transfer the heat from the primary source to the organic working fluid of the ORC cycle. As the organic fluid heats up, it vaporises and passes through Exergy's high-efficiency ROT turbine, generating electricity.

The solution designed by Exergy provides a dual advantage: the ORC system repurposes exhaust heat to generate carbon-free electricity while simultaneously replacing the overhead condenser, used in the typical layout of the chemical plant. This dual functionality makes the system both efficient and cost-effective.

The ORC is fully integrated with the customer's process but does not interfere with chemical manufacturing operations, ensuring no impact on PET production capacity or rates, even during start-up and shutdown phases.

The electricity generated by the ORC plant is employed for internal consumption, meeting 20% of the factory's energy needs. The plant has been operating since October 2023. It is estimated to contribute to an annual CO_2 emissions reduction of approximately 20,000 tons, also avoiding the consumption of 8,500 tons of oil equivalent per year by replacing electricity from fossil fuels.

The plant underwent a technical evaluation by an external committee of academicians from the Chinese Academy of Engineering and senior engineers from independent engineering companies. The evaluation highlighted an impressive thermoelectric efficiency of 11.22% and an isentropic turbine efficiency of 88.69%.

Return on investment

An ORC waste heat recovery system installation in the industrial sector has a typical payback time of four to eight years depending on variables such as the electrical output of the ORC required, the plant configuration, the selling price of electricity and others. Incentives like carbon credits and additional premiums for saved CO_2 emissions can further shorten this period.

For the Sanfame project, the waste heat recovery system demonstrates an advantageous payback time, expected in three years.

Conclusion

Waste heat recovery systems are proven solutions for reducing the environmental impact and energy costs of energy-intensive industries. By decreasing reliance on fossil fuels, these systems also significantly cut carbon emissions, covering up to 30% of industrial energy needs.

VIEW REFERENCES

Sara Milanesi
s.milanesi@exergy.it