LNG INDUSTRY

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Exergy International explores how new developments can help the decarbonisation of LNG regasification.

UNTAPPING COLD ENERGY POTENTIAL

As the deployment of renewables and new technologies advances towards a net-zero transition by 2050, fossil fuels continue – and will continue – to play a critical role in ensuring a stable, dispatchable baseload energy supply via existing grids. Among them, natural gas (as the most sustainable option) serves as a key transition fuel. In particular, LNG is set to play a pivotal role thanks to its exceptional transportability via sea routes, which allows LNG to be sourced from a wide range of producing countries, offering unparalleled geographical and market flexibility.

According to the International Energy Agency (IEA)'s *Global Gas Security Review 2024*, the global gas demand is expected to rise by 2.3% (approximately 100 billion m^3) in 2025, with Asia continuing to be the main driver, accounting for more than one-half of the increase in demand.[1] At the same time, LNG supply growth is projected to accelerate to nearly 6% (30 billion m^3) in 2025, thanks to the launch of several large LNG projects. North America is forecast to contribute around 85% of the global increase in LNG supply in 2025.

Harnessing waste heat for sustainable LNG regasification

LNG is experiencing significant growth and holds substantial potential for power generation. However, the process of liquefying natural gas is highly energy-intensive, requiring substantial electricity consumption – about 500 kWh/t of LNG produced, which represents approximately 3.6% of natural gas' lower heating value (LHV). After liquefaction, LNG is converted back to its gaseous state through vaporisation, a process that also consumes significant energy. In fact, up to 28% of the energy used during liquefaction is lost to the environment.

The exhaust heat generated by gas turbines utilised in the regasification process can be captured and reused to improve overall system efficiency and sustainability. By implementing waste heat recovery systems, the thermal energy discharged by gas turbines can be harnessed to generate electricity to power additional processes, reducing overall fuel consumption and minimising the environmental impact of the operation.

One effective way to capture and utilise this waste heat is through Organic Rankine cycle (ORC) technology. An ORC system is a closed thermodynamic cycle designed to generate power from low to medium-high temperature heat sources, ranging from 90˚C – 400˚C, and for small to medium scale applications at any temperature level. The ORC system works similarly to the widely used Clausius-Rankine cycle, but instead of water (steam), it uses organic substances like hydrocarbons or refrigerants as working fluid. ORC is particularly suitable for waste heat recovery, as it efficiently converts low-grade heat, such as the exhaust heat from gas turbines, into usable power.

In the ORC system, the waste heat source is directed into a sequence of heat exchangers, where it vaporises an organic working fluid. The high-pressure vapour expands in the turbine, which drives an electric generator, before being discharged into the condenser. Here, the heat is released to the LNG, facilitating its vaporisation until it returns to a gaseous state. The cycle operates within a closed loop, with no additional fluid makeup required, and is sealed to ensure efficiency.

The main components of an ORC system include a heat exchanger within the gas turbine's exhaust system, a turbine powering an electric generator, a water-cooled or air-cooled condenser, and a feed pump. Air cooling is normally preferred to avoid water usage or potential water supply limitations. Occasionally, a recuperator is used to extract remaining heat from the turbine discharge stream before it enters the condenser, preheating the fluid between the pump and the primary heat exchanger. The selection of the working fluid is crucial and is determined through parametric analysis to optimise thermodynamic performance and minimise environmental impact. Cyclopentane, a hydrocarbon fluid, has been identified as one of the most suitable working fluids for large scale applications, due to its effective environmental properties, including zero ozone depletion potential (ODP) and zero global warming potential (GWP).

By efficiently recovering waste heat, ORC systems can significantly enhance the sustainability of LNG operations, contributing to a more energy-efficient and environmentally-friendly energy production process.

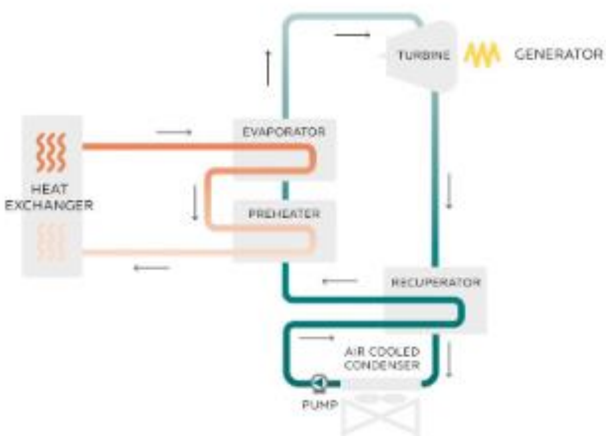

Figure 1. Organic Rankine cycle diagram.

Figure 2. 3D image of an ORC waste heat recovery unit with its components.

Figure 3. Radial outflow turbine rotor disk.

Innovation in ORC systems

Exergy International has been at the forefront of engineering ORC systems for energy efficiency in various sectors. While axial and radial inflow turbines have traditionally been the standard for ORC systems, Exergy developed this approach by introducing the radial outflow turbine (ROT) to the ORC cycle in 2010. This technology, which remains exclusive to the company's ORC systems, offers improved performance and efficiency due to its configuration and patented components.

Employing the ROT technology in an ORC system offers several advantages. It provides up to a 6% higher efficiency over axial turbines, due to key design improvements. The ROT features up to nine stages on a single disk, reducing the size and length of the turbine compared to axial turbines. This design also results in less tip leakage and reduced disk friction losses. Additionally, the low blade height and minimal blade height variation lead to a significant reduction in 3D fluid-dynamic losses.

The ROT operates at a low rotational speed (3000 – 1500 rpm), eliminating the need for a gearbox and allowing direct coupling with a two or four-pole generator. This direct coupling enhances the reliability of the overall system.

Maintenance is also more straightforward and cost-effective. The mechanical group of the turbine, including bearings, oil lubrication systems, and seals, can be easily removed without the need to drain the organic fluid from the cycle. This design allows for reduced downtime, with maintenance typically taking less than one day, compared to the longer downtimes, a week or more, associated with other turbine technologies.

With over 60 installations worldwide, including more than 20 in waste heat recovery applications, Exergy has implemented heat recovery projects to generate clean electricity.

Case study: Thailand

One notable application in the LNG sector can be found in Thailand, where Exergy's technology was implemented to optimise energy efficiency in a LNG regasification terminal.

In 2019, Exergy, in partnership with Baker Hughes, supplied Samsung Engineering as EPC contractor with its first ORC with ROT technology at an LNG regasification terminal in Rayong, Thailand, by PTT LNG. The company aimed to enhance the efficiency and sustainability of their operations and Exergy provided a solution that successfully met these goals. The plant recovers the exhaust heat produced by the two solar mars 100 gas turbines in the LNG plant. This heat is used to generate 5 MWe of electricity, helping offset the terminal's energy demands. The ORC is water cooled, repurposing the water used in the regasification process to feed the ORC condenser, thus ensuring no additional water consumption. All components of the ORC system were designed in compliance with API technical standards, requiring Exergy to collaborate closely with the manufacturing team to meet market specifications. This project exemplifies how waste heat recovery can enhance the efficiency of LNG regasification, providing an eco-friendly solution generating valuable clean electricity that can be employed for on-site energy demand.

While improving the energy efficiency of the operation, this solution also helps mitigate Scope 2 carbon dioxide emission by reducing the fossil-fuel energy demand.

Advancing LNG applications

Starting from 2021, Exergy expanded its research to explore the ROT's potential for application in LNG regasification processes. After years of R&D activities, Exergy launched its cold energy plant (CEP) in 2023 to leverage the cold energy potential in LNG regasification processes. The CEP system is an ORC which introduces a notable development, the patented multi-level condensation cycle designed specifically for cold energy recovery in LNG applications. This aims to maximise the utilisation of the LNG heat sink along the vaporisation curve, thereby enhancing cycle efficiency and maximising electrical power production at the required regasification rate. The patented design accommodates up to four levels of condensation, employing a single feed pump in the ORC circuit and the company's ROT.

Benefits of Exergy's multi-level condensation with a single feed pump include:

- Achieving higher cycle efficiency, increased specific power production (SPP), and a greater cold energy recovery factor compared to single-level systems.

Figure 4. The turbine for PTT LNG's plant.

Figure 5. PTT LNG regasification plant in Rayong, Thailand.

- Enabling a single pump configuration using a throttling valve at the outlet of high-pressure condensers. Utilising a single, low suction pressure pump results in lower ORC plant complexity and CAPEX, fewer critical equipment exposed to cryogenic temperatures, anticipated fewer maintenance stops, and increased plant annual availability.
- Integration with high-efficiency ROT, which naturally facilitates spillages between stages, allowing for both high-pressure and low-pressure expansion within a single turbomachine unit.

Advantages of the ROT for cryogenic applications:

- High efficiency: The ROT performs efficiently under both on-design and off-design conditions due to its optimised velocity triangles and multiple reaction stages.
- Single disc turbine: Capable of handling multi-level condensation pressure levels in a single machine, eliminating the need for multiple turbines.
- Spillage point clearance: The ROT's shaft length does not require expansion for spillage point clearance, avoiding rotor dynamic issues common in axial turbines.
- Direct drive: The ROT's low rotational speed enables direct drive, eliminating the need for a gearbox.

LNG's cold energy potential remains largely untapped, with less than 1% of its overall potential currently being utilised. This vast reservoir of cold energy, along with the mechanical energy derived from the regasification process, represents a largely unexplored opportunity. By efficiently capturing and utilising both the waste heat and cold energy from LNG, ORC technology can significantly enhance the sustainability of LNG operations.

Conclusion

LNG plays a key role in the transition to a sustainable energy future, offering a cleaner alternative to fossil fuels. As global LNG demand grows, Exergy's plant and the strategic implementation of ORC systems provides a critical solution for decarbonising LNG regasification, improving the sustainability of processes to support a low-carbon future.

While regasification remains energy-intensive, technologies such as waste heat recovery and cold energy utilisation offer significant potential for improved efficiency and reduced environmental impact. Advanced regasification methods also ensure reliable energy distribution. **LNG**

References

1. 'Global Gas Security Review 2024', *International Energy Agency*, (3 October 2024), www.iea.org/reports/global-gas-security-review-2024