R&D pathways for dispatchable net zero power and heat solutions

Gas turbines will play a pivotal role in the ongoing energy transition. A recent milestone was reached in the collective effort required to realise the vision of a decarbonised energy system, with the publication of ETN Global's report on the latest research and development in the sector. ETN's **Christer Björkqvist** discusses some of this R&D work as well as pathways for the use of gas turbine systems for power generation and mechanical drive.

Björkqvist: It is imperative to foster an informed and coordinated voice within the gas turbine user community

The global energy landscape is undergoing significant changes, characterised by increasing complexity and volatility. Factors such as disruptions in supply chains, inflationary pressures, and global economic turmoil have posed threats to energy security and affordability. Additionally, the escalating global temperature and the rise in natural disasters across the planet are pressing challenges our society urgently needs to address. Consequently, there is a need to accelerate decarbonisation efforts in line with the 2030 targets and the goal of net zero emissions by 2050.

All of this must be done while ensuring the security of energy supply and promoting energy equity. Various decarbonisation technologies and solutions are under consideration, each with its unique advantages and drawbacks. It is therefore crucial to thoroughly explore future scenarios and pathways in a system approach to define a portfolio of technologies and solutions that can be tailored to overcome the complexity of the energy trilemma.

Increasing the share of renewable energy is the main pathway for decarbonising the energy grid. Recently, the European Parliament voted in favour of raising the share of renewables in the EU's final energy consumption to 42.5 per cent by 2030. But considering the intermittent nature of renewables such as wind and solar, integrating reliable and dispatchable power and heat technologies becomes imperative.

The dispatchability and adaptability to use carbon-free fuels make gas turbines an essential technology in decarbonisation strategies. Gas turbines already offer high efficiency, reliability, operational flexibility, well-established low-emission credentials, and the capability to use hydrogen fuel blends. These attributes offer important decarbonisation opportunities in the energy transition, and a clear path towards a dispatchable zero-carbon technology suited for a wide variety of applications along with the opportunity of additional efficiency increases through sector coupling. As such, continuous research and innovation efforts in the gas turbine sector are of paramount importance to exploit the full capabilities and potential contributions of turbomachinery technologies in the energy transition and beyond.

The ability to utilise hydrogen/methane blends today and the prospect of using 100 per cent hydrogen and even carbon-negative fuels within the next decade have reshaped the industry. For this purpose, new combustion techniques are under development, e.g., staged combustion and micro-mix combustion. These combustion techniques require significant changes in the architecture of the gas turbine combustion system, and thus need major R&D steps before they can be considered in commercial gas turbine products.

Impressive achievements are already underway, and several full-scale R&D projects are ongoing to demonstrate 100 per cent hydrogen combustion. This evolution not only aligns with carbon reduction goals but also addresses the critical need for energy storage as variable renewable energy sources expand.

The European Commission's commitment through the European REPowerEU programme to make 20 million tonnes of renewable hydrogen available by 2030, is ambitious and holds great potential to kick-start the development of a hydrogen economy also for power generation.

Other alternative fuels that are close in composition and properties to natural gas, such as biofuels/methane and Synthetic Natural Gas (SNG), are also expected to play a key role. These fuels can be derived from sources like waste biomass, or synthesised using surplus renewable energy. The use of biodiesel and biogas has been fully demonstrated in a wide range of gas turbine engines and the development of fuel systems is ongoing to improve fuel flexibility even further. Ammonia is another carbon-free alternative gaining prominence, serving as both an intermediate vector for hydrogen transport and a potential fuel for gas turbines. However, to use ammonia as a gas turbine fuel requires major changes to the fuel and combustion system due to the lower heating value, flame speed and higher nitrogen content. Constant and promising progress is being reported also on this challenge.

Carbon capture, utilisation and storage (CCUS) solutions are also a decarbonisation pathway of importance, especially for industries struggling with "hard-to-abate" emissions, which require additional demonstrations. Following successful feasibility studies, the UK and US are advancing in the Front-End Engineering Design (FEED) phase. During this stage, engineering designs for power stations capable of capturing approximately 95 per cent of carbon dioxide emissions are being developed, with the aim of achieving commercial deployment by 2030.

By using dispatchable gas turbine-based power generation operating on carbon-neutral or decarbonised fuels, coupled with existing gas infrastructure and seasonal energy storage solutions, the required electricity supply and grid stability can effectively be guaranteed in a sustainable way. This integrated approach paves the way for the seamless large-scale integration of intermittent renewable energy sources.

To fully explore this pathway, increasing the operational flexibility with improved ramp rates and enhanced load-following capabilities becomes crucial, particularly with increased efficiency at part-load.

Integration of energy storage solutions in thermal power plants is another way to increase ramp capabilities and allow operation at nominal maximum and minimum loads while maintaining the possibility of providing ancillary grid services. There are many different schemes that might be integrated, including thermal energy storage, compressed air energy storage, liquified air energy storage, batteries, or power-to-X-to-power schemes.

Such an integrated system would further improve flexible plant operation in peaking mode, increase ramp rate/frequency response and minimise complete machine shutdown, therefore potentially reducing mechanical fatigue. The hybridisation with batteries could provide another advantageous opportunity by replacing traditional black-start engines with electric motors. Hydrogen, supplements batteries allowing for extended storage ranging from days to seasons, making it an ideal complement to intermittent renewables.

R&D efforts are also required to enhance the flexibility of entire power plants, including the bottoming cycle. In this regard, emerging technologies such as Organic Rankine Cycles and CO_2-based cycles with various cycle configurations, aim to replace the classical water-steam bottoming cycle. Testing of subcomponents is currently ongoing.

Micro and small gas turbines are gaining prominence in decentralised energy systems, offering the ability to stabilise low- and mid-voltage power grids while reducing the burden on high-voltage networks. In decentralised systems, there is no need for long-distance energy transportation, as they are using local biomass, renewable energy sources, and locally generated hydrogen. Implementing gas turbines in combined heat and power applications can effectively lower primary energy consumption, covering both the electricity and the heating demand.

While gas turbines ranging from 2 MW to 20 MW are well-established in industrial settings, micro gas turbine (MGT) technology, typically operating within the range of 1 kW to 1 MW and employing the recuperated Brayton cycle, holds promise for decentralised power generation among smaller consumers. Commercial MGTs feature mid-low power-to-heat ratios, making them optimal for heat-driven cogeneration applications. Considering the ongoing electrification trend and the growing demand for decentralised solutions, future MGTs will also need to demonstrate higher efficiency in electricity-driven applications.

There is a growing need to explore the potential of digitalisation, automation and analytics to enhance the reliability and optimisation of power plant operation and maintenance. Lifetime assessment and extension of critical components to control and mitigate potential effects of increasing starts and stops, cyclic behaviour and the use of alternative fuels are becoming increasingly important.

To further mitigate the risk of material and component fatigue a focus on design developments is essential. Particularly in areas such as flow path optimisation, advanced material selection, and expanded repair options. Furthermore, optimising operations through increased accurate measurements not only reduces fuel consumption but also lowers CO_2 emissions. While these technologies are already available, there is a clear need and opportunities for ongoing improvements.

Emerging additive manufacturing techniques, such as laser metal deposition have opened new possibilities for designing complex 3D burners and combustors. Other 3D printing techniques and new high-temperature materials are also being explored by OEMs, suppliers and operators for the manufacturing and repair of parts. These efforts aim to reduce costs and achieve unique material compositions or structures that are otherwise unattainable through conventional 'subtractive' manufacturing methods. Additionally, the identification and validation of high-temperature alloys using the laser powder bed fusion (LPBF) process are essential steps needed for additive manufacturing of turbine blades.

As global energy markets continue their transformation, gas turbine technology retains its central role, offering adaptability, versatility, and decarbonisation potential, critical to building a resilient and sustainable energy system. To expedite this adaptation, it is imperative to foster an informed and coordinated voice within the gas turbine user community, guiding and stimulating market demand.

To progress towards this, ETN Global, a leading international association representing the entire gas turbine value chain, features dedicated technical Working Groups, led by a Project Board that considers input from the gas turbine user community and aligns with policy targets. The outcomes are common cooperation activities like projects, standardisation, and reports detailing the R&D described and technology roadmaps.

ETN Global plays a pivotal role as a platform for collaboration among the gas turbine users, the research and development community, and technology providers. A key outcome is the identification of a portfolio of solutions, including the most promising development pathways for diverse markets, applications, and geographical locations. Ultimately accelerating the technology transition through a more focused approach.

The R&D report will be made publicly available on ETN's website www.etn.global after the International Gas Turbine Conference 10-11 October 2023.