Drawing a Carbon-Neutral Future:
Hanwha Power Systems' Ammonia Gas Turbine

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The mid-term GHG reduction measures were decided at the 83rd MEPC meeting. While various fuel options are being discussed, the possibility of using multiple alternative fuels in parallel is being raised due to supply uncertainties. In this context, how do you assess the importance of ammonia fuel?

The mid-term GHG reduction measures agreed upon at the 83rd MEPC session mark a major turning point in accelerating the decarbonization of international shipping. The position of LNG, once considered a relatively eco-friendly fuel, is weakening, while demand for alternative fuels such as bio-fuels, methanol, ammonia, and hydrogen is expected to increase rapidly and gradually replace traditional fossil fuels. As a result, investments in stable production and supply of alternative fuels, securing price competitiveness, and developing related equipment and systems will be accelerated. Among these alternative fuels, ammonia stands out as a fuel with significant advantages in terms of production, transport, storage, and infrastructure. While its inherent toxicity and corrosiveness pose safety challenges, if these can be overcome through technological development and thorough validation, ammonia, as a carbon-free fuel, could achieve complete decarbonization. Additionally, its compatibility with existing production infrastructure and supply chains, along with its relative ease of storage and transport, positions it as a strong candidate not just as an interim fuel but as a fundamental solution for Zero or Near-Zero (ZNZ).

There is significant industry interest in Hanwha Power Systems' development of ammonia gas turbines. Could you briefly introduce the background or motivation for starting this project and the progress made so far?

Hanwha Power Systems, in collaboration with Hanwha Impact, successfully completed a hydrogen demonstration on an 80 MW mid-to-large-scale gas turbine in 2023 as part of our 100% hydrogen capable combustion system development program. While exploring sustainable and eco-friendly solutions not only for land-based power generation but also for the marine and offshore sectors, we decided to leverage the capabilities of our affiliates to initiate the development of an ammonia gas turbine with for electric propulsion in ships. Ammonia gas turbines offer several notable advantages as follows: they do not require a single drop of pilot oil during normal operation; they demonstrate excellent fuel flexibility, supporting both 100% ammonia and 100% natural gas (NG) combustion, and ammonia-NG co-firing in various ratios; they produce almost no methane slip, ammonia slip, or N_2O emissions, and can meet Tier III NOx standards for large low-speed engines without the need to install the Selective Catalytic Reduction (SCR) systems; their compact footprint allows ammonia fuel to be stored without sacrificing cargo space; and they are designed with built-in enclosures in depression and ventilation systems to address safety concerns related to ammonia fuel. We believe this technology could be revolutionary in the maritime sector, which

has traditionally been dominated by internal combustion engines. Moreover, we are expanding development to target other markets such as land-based power plants and offshore platforms.

To this end, Hanwha Power Systems and Hanwha Ocean signed a joint development agreement with Baker Hughes, an energy technology company, to develop a new small-size turbine for ammonia applications in February of this year.

PSM – Hanwha Power Systems sister company based in Florida, USA - is developing the ammonia combustor, and they successfully completed a second ammonia full pressure test in March of this year.

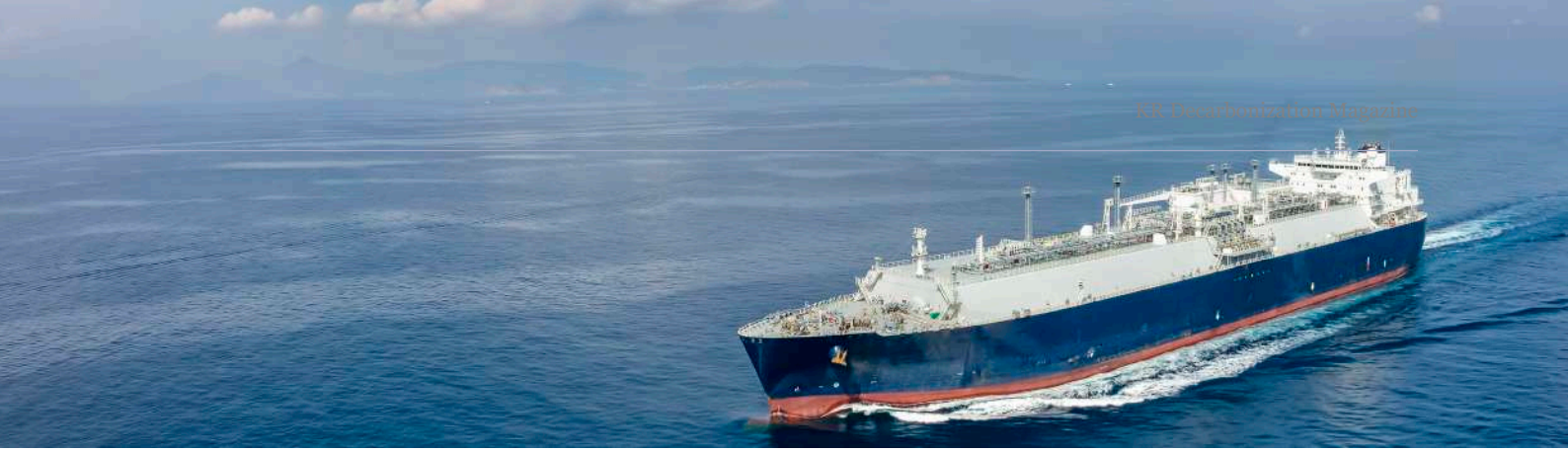
" Hanwha Power Systems is currently focusing on developing marine gas turbine packages and establishing a dedicated testing facility, with the goal of completing full engine test with ammonia by the end of 2027 and delivering it to shipyards. "

For which types of vessels is the ammonia gas turbine expected to be most competitive?

When we began developing the ammonia gas turbine in early 2023, our primary target was LNG carriers of 174,000 cubic meters or larger. Since the turbine is being developed to allow both full ammonia and full NG combustion—as well as co-firing at any desired ratio—it can economically utilize Boil-Off Gas (BOG) from the LNG cargo tanks as fuel. At the same time, blending with ammonia allows the vessel to comply with increasingly stringent environmental regulations, avoiding penalties and potentially earning compliance incentives.

However, we've recently seen significant interest from container carriers as well. Large container ships require high power output for both propulsion and onboard electricity, making them eager for fundamental solutions that use alternative fuels compliant with environmental regulations. Unlike LNG carriers, however, container ships require additional installations to use LNG fuel and face complications in bunkering, leading many operators to prefer fuel oil (FO) for start-up or supplementary fuel. In response, we are now considering a derivative version of the ammonia gas turbine that can start and co-fire with FO instead of NG. This diversification of start-up and co-firing fuels could make ammonia gas turbines applicable to a broader range of vessels, including container ships, Very Large Ammonia Carriers (VLACs), and Very Large Crude Carriers (VLCCs). If FO is replaced with bio-diesel or similar fuels, a fully carbon-free operation—from start-up to full power—can be achieved.

We also believe there's economic feasibility in retrofitting relatively new vessels with ammonia gas turbines, and we are conducting various reviews to explore this possibility.



How do you assess the market potential and economic viability of ammonia gas turbines?

If there were no environmental regulations, it would be difficult for any vessel or engine using alternative fuels to secure an economic advantage over Heavy Fuel Oil (HFO) and conventional internal combustion engines. However, the mid-term GHG reduction measures adopted at MEPC 83 have sent a clear message to the market. Unlike previous regulations like the EU ETS and FuelEU Maritime that were limited to the EU, the IMO has now established a foundation for regulations applicable to ships worldwide. This shift means that environmental compliance costs must now be factored into any genuine assessment of economic viability. Furthermore, the incentive scheme for ZNZ fuels, to be agreed upon in 2027, is expected to serve as an effective driver to accelerate the transition to carbon-free fuels like ammonia.

If infrastructure for ammonia fuel production and bunkering continues to develop rapidly and related safety concerns are sufficiently addressed within this paradigm shift, shipowners' perceptions will evolve, leading to ammonia gas turbines being well positioned as a highly competitive emerging technology.

There are concerns about the harmful effects of ammonia on human health, making safety a critical issue when used as marine fuel. How is Hanwha Power Systems addressing these safety concerns?

Ironically, safety concerns about ammonia fuel are one of the reasons we are developing ammonia gas turbines —gas turbines offer an inherently safer system for utilization of ammonia fuel. As previously mentioned, the compact footprint of a gas turbine allows it to be installed within its own enclosure, equipped with a dedicated ventilation system that maintains negative pressure inside the enclosure at all times. To help shipowners understand this setup more intuitively, we often describe it as a "double engine room"—an engine room within the engine room.

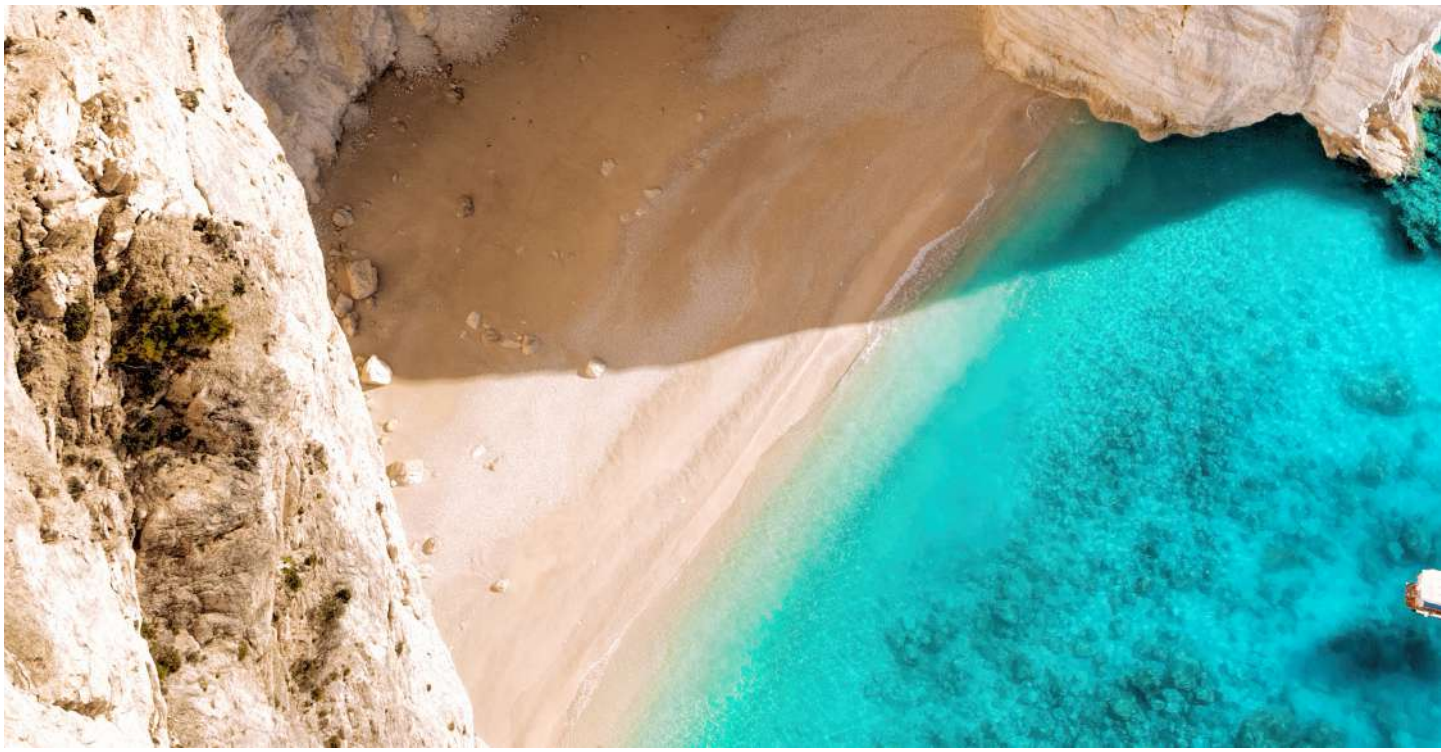
In addition, we are incorporating high-performance sensors for leak detection and implementing multiple layers of protective systems. The fuel storage and transfer lines are designed with double-

walled piping, automatic shut-off valves, and emergency ventilation systems. We are also strictly complying with the IMO's International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels (IGF Code) and International Code of the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code). At the same time, we are conducting scenario-based risk analyses to ensure safe ship operations and to protect crew members.

While ammonia combustion can reduce GHG emissions, there are also concerns about exhaust gas issues such as ammonia slip. Could you elaborate on the environmental advantages of this gas turbine technology?

Methane slip and ammonia slip from propulsion and power generation systems are critical environmental or safety concerns. In the case of engines, additional devices are often required to manage methane slip, and ammonia slip poses significant safety risks, requiring careful handling. Gas turbines, however, operate through continuous rotational motion and combustion, which inherently reduces the likelihood of incomplete fuel combustion.

" As a result, methane and ammonia slips are negligible. In the second combustion test conducted this past March, we confirmed that both methane and ammonia slips were virtually undetectable even without any additional after-treatment systems. "



There is a general perception that gas turbines are less thermally efficient than internal combustion engines. Given this, there may be concerns about fuel efficiency when using ammonia. What strategies or technical solutions is Hanwha Power Systems implementing to address this?

Gas turbines do typically have lower thermal efficiency in independent operations compared to internal combustion engines. However, when configured as part of a Combined Cycle System—paired with waste heat recovery technologies like steam turbines or supercritical CO_2 (sCO_2) cycles—the overall system efficiency can be significantly improved. While their efficiency may not exceed that of low-speed engines which are currently dominant in the market, ammonia gas turbines are expected to offer higher efficiency than medium-speed generator engines. Hanwha Power Systems, in collaboration with Baker Hughes and PSM, is continuously working to further improve gas turbine efficiency. We are optimizing the overall system, including waste heat recovery units and fuel supply systems, to enhance performance from a holistic perspective.

Moreover, since gas turbines are used in conjunction with electric propulsion systems, they can be operated in optimal combinations with fuel cells and batteries. This allows us to overcome the relative efficiency disadvantage of the turbine itself by designing a highly efficient and more integrated overall system.

Ammonia is being recognized as a key fuel for decarbonization, and in the future, it will likely face competition from internal combustion engines and fuel cells that also use ammonia. What is your outlook on the competitiveness and market positioning of ammonia gas turbines?

As mentioned earlier, ammonia gas turbines offer several distinct advantages over ammonia engines. These include the ability to operate without pilot oil, enabling fully carbon-free operation, superior fuel flexibility with the capability to co-fire with NG, a compact footprint that simplifies the installation of ammonia fuel tanks, and the use of enclosed systems that mitigate safety concerns related to ammonia handling. Additionally, they produce minimal noise and vibration, and they do not require exhaust after-treatment systems like Selective Catalytic Reduction (SCR) to reduce NOx levels below the IMO Tier III standard. Unlike fuel cells, ammonia gas turbines do not need to crack ammonia into hydrogen, which is a very energy intensive process, as they can use ammonia directly as fuel. Their power output is also sufficient to serve as a main propulsion system, giving them a clear advantage over fuel cells. If ammonia becomes the dominant alternative fuel, ammonia gas turbines are expected to secure a strong competitive edge in the market.

Despite the many strengths of ammonia gas turbines, what are some of the challenges that still need to be overcome?

While the advantages are significant, there are two key challenges that still need to be addressed.

The first challenge to be tackled is the stable supply and global bunkering infrastructure for blue or green ammonia. This is expected to accelerate over time, and we believe that as the related technologies mature, price competitiveness will also improve. To help complete the entire value chain from upstream to downstream, we are actively building networks and engaging in discussions with various partners.

The second challenge is the relative unfamiliarity of ammonia fuel and gas turbine systems among shipowners and crew. To address this, we plan to provide comprehensive manuals and intensive training programs to ensure safe operation and maintenance. We are working with Baker Hughes and Hanwha Ocean to prepare these effective methods.