Hydrogen/Ammonia-fired Gas Turbine Initiatives for Carbon Neutrality

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Toward the goal of achieving carbon neutrality by 2050, Mitsubishi Heavy Industries, Ltd. (MHI) is expanding its line-up of carbon-free power generation systems. With regard to gas turbines using hydrogen, the development of a gas turbine combustor that can operate on a blend of 30 vol% hydrogen and natural gas has been completed. Combustion tests have been conducted on a combustor with hydrogen dry single-firing and the development is in progress toward practical application. Furthermore, for gas turbines using ammonia, the combustion system is currently in development to enable 100% ammonia to be fired in small-to-middle gas turbines. These power generation systems will be verified one by one through actual-unit demonstration testing by 2025 with the aim of realizing their early commercialization.

1. Introduction

Achieving net-zero emissions of carbon dioxide (CO_2) around 2050 is becoming the world's common goal. Countries do not remain in the stage of setting ambitious targets. They have now entered the stage of executing action plans to fulfil their targets. In Japan, the energy sector is attributable to more than 80% of the greenhouse gas emissions. While electricity is mainly converted from primary energy, the Sixth Strategic Energy Plan has set the energy sector to work toward the goal of hydrogen and ammonia serving as a power source accounting for 1% of the electricity generated in 2030[(1)].

MHI has declared "MISSION NET ZERO" and is promoting thereunder decarbonization from the perspectives of both energy transition and the smartification of social infrastructure to achieve carbon neutrality. As shown in **Figure 1**, decarbonization through energy transition focuses on "reducing," "capturing" and "eliminating" CO_2 emissions from thermal power plants. Specifically, it includes (1) CO_2 reduction by replacing the coal-fired systems with the low-carbon and high-efficiency gas-fired systems (GTCC : Gas Turbine Combined Cycles) and promoting the application of hydrogen co-firing in gas turbines and ammonia or biomass co-firing in coal-fired systems, (2) promotion of utilizing Carbon dioxide Capture, Utilization and Storage (CCUS) by optimizing the entire power plant that is equipped with GTCC and CO_2 capture equipment, and (3) promotion of adapting gas turbines to use new fuels with a view to hydrogen (H_2) or ammonia (NH_3) single-firing, neither of which emits CO_2. The development under the sponsorship of New Energy and Industrial Technology Development Organization (NEDO) is moving forward regarding the hydrogen co-fired combustor for large gas turbines in which 30 vol% hydrogen is blended with natural gas, and the combustor with hydrogen dry single-firing. The development of a GTCC system using ammonia has also started. As shown in **Table 1**, the line-up of carbon-free gas turbine systems is expanding. MHI aims to achieve decarbonization through energy transition with these power generation systems by 2030.

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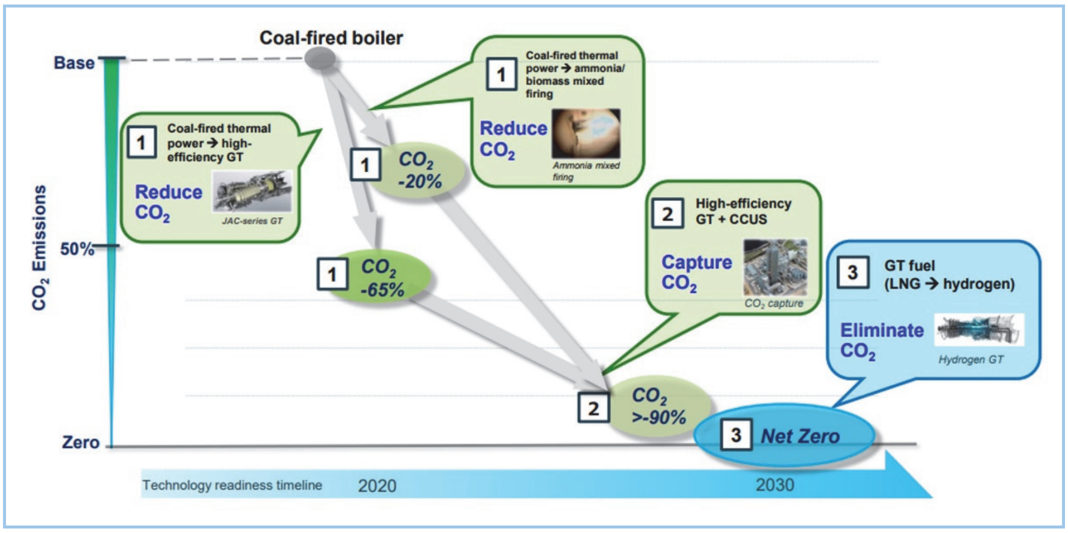


Figure 1 MHI's Initiatives for decarbonization of thermal power generation infrastructure

Table 1 MHI product line-up of carbon-free gas turbine systems

Equipment		Summary	Availability
Hydrogen gas turbine	30% co-firing	A blend of 30 vol% hydrogen and natural gas is fed into a natural gas-fired, low-NOx combustor. Applicable without any changes in existing gas turbines or with minimum retrofitting.	Development completed in 2018
	Single-firing	A multi-cluster combustor for hydrogen single-firing is in development.	Development to be completed in: 2025 for large frame GT 2023 for small frame GT
Ammonia cracking GTCC		Waste heat from a gas turbine is used to decompose ammonia into H_2 and N_2. The former is then used as a fuel for the gas turbine. It is possible to co-fire natural gas and the product gases from ammonia decomposition (H_2 and N_2), or fire only these product gases. Suitable for the application to large units with high-temperature waste heat.	In development
Ammonia direct-fired GTCC		The system remains simple, because no cracking equipment is needed. Ammonia combustion involves generating NOx in large quantities, requiring a dedicated combustor to be developed. NOx removal equipment for exhaust gas is also essential.	Development to be completed in 2024 before aiming for verification

Hydrogen is considered the most effective carbon-free fuel in replacing or supplementing fossil fuels. This is because hydrogen has a high potential for converting existing fossil fuel equipment and systems into carbon-free alternatives while keeping them operating. In the value chain including hydrogen production, transportation, storage and utilization, large-capacity and high-efficiency hydrogen-fired gas turbines give the following advantages for those who aspire to achieve carbon neutrality: (1) low-carbonization or decarbonization of existing gas turbine facilities is possible with minimum retrofitting and the lowest investment costs, (2) hydrogen is expected to become cheaper as a result of growing hydrogen demand on a large scale, because a single power generation facility with a large hydrogen-fired gas turbine (hydrogen single-firing) at an output of 500 MW class requires hydrogen equivalent to 2 million fuel cell vehicles, (3) not only liquid hydrogen but also various types of hydrogen carriers such as methylcyclohexane and ammonia can be handled, and (4) the high start-up and load-changing (ramp rate) capabilities of gas turbines, which can follow sudden variable renewable energy output (influenced by weather and seasons), can flexibly balance the gap between the electricity demand and the supply capacity of renewable energy.

However, there are some difficulties with hydrogen, namely, mass transportation and storage. Japan largely depends on imported energy. If a hydrogen society is to be realized in Japan, the use of ammonia is considered to be another effective means. Among the carriers for hydrogen transportation and storage, ammonia has a higher volumetric hydrogen density than liquid hydrogen or methylcyclohexane, therefore enabling efficient hydrogen transportation and storage. Ammonia is also advantageous in terms of handling, as the existing transportation/storage infrastructure can be used for it. Furthermore, it is possible to directly burn ammonia as a carbon-free fuel. If GTCCs are able to be introduced ammonia at an early stage, it will become a promising carbon-free fuel of the future.

Focusing on hydrogen or ammonia-fired gas turbines among MHI's projects for carbon neutrality, this report presents the development status of the main items (i.e., gas turbine combustors and combustion technologies) and the schedule for their validation.

2. Development status of hydrogen or ammonia-fired gas turbines

2.1 Challenges of combustion hydrogen and ammonia

The conversion of a gas turbine from natural gas firing to hydrogen/ammonia firing becomes possible by adding a new combustor and fuel supply system, and is therefore characterized by the minimum retrofitting as the main body can continue to be in use. Therefore, the development of gas turbine combustor and combustion technology is the key to success in developing a hydrogen or ammonia-fired gas turbine.

Figure 2 shows the combustion types and features of MHI gas turbine combustors. In diffusion combustion, fuel and combustion air are injected separately into the combustor. Compared with the premixed type, there are more localized rises in the flame temperature within the combustor, and nitrogen oxides (NOx) emissions are increased. It is therefore necessary to take measures by injecting steam/water and reduce NOx emissions. On the other hand, the stable combustion range is relatively wide, and the tolerance for fuel property fluctuations is large.

In premixed combustion, fuel and air are mixed in advance before being fed into the combustor. Compared with the diffusion type, the pre-mixed system can reduce local rises of flame temperature in the combustor. NOx reduction measures such as steam/water injection are therefore unnecessary, and there is no decline in the cycle efficiency. Because of its capability of simultaneously achieving low NOx and CO_2 reduction (high efficiency), the premixed type is used as the base for the development of hydrogen/ammonia-fired combustor. However, the stable combustion range is narrow, there are risks of combustion instability and flashback, and unburned fuel tends to be discharged.

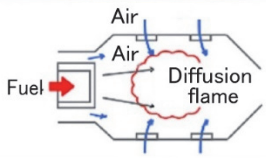
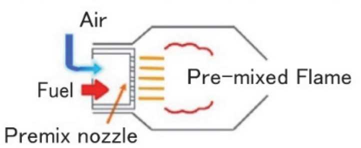
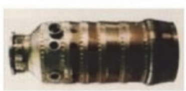
Type	Diffusion combustion	Premixed combustion
Configuration	 Air, Air, Fuel, Diffusion flame	 Air, Fuel, Pre-mixed Flame, Premix nozzle
Combustion Characteristics	・Fuel and Air are injected individually. ・High gas temperature (High NOx) ・Stable flame	・Fuel and Air are mixed before combustion. ・Low gas temperature (Low NOx) ・Unstable flame (Risks of combustion instability and flash back)
Specification	・Wide allowable range of fuel ・Simple fuel supply system ・Low efficiency due to steam and N_2 injection	・Establishing both low NOx abd high efficiency ・Complicated fuel supply system
Combustor	Diffusion combustor 	Multi-nozzle combustor  Multi-cluster combustor 

Figure 2 Diffusion and premixed combustion systems

Figure 3 compares natural gas which contains methane (CH_4) as the main component and is the most common fuel used in gas turbines, hydrogen and ammonia in terms of their lower heating values and burning velocity. Hydrogen has a higher lower-heating value and a higher burning velocity than methane; hydrogen burns about seven times quicker. When natural gas and hydrogen are co-fired in a premixed combustor or 100% hydrogen single-fired, the flame position moves further upstream than when only natural gas is fired. This results in the high flame temperature combustion occurring before fuel is sufficiently mixed with air, which leads to an increase in NOx production. There is also an increased risk of flashback by which the flame traveling upstream of the combustor burns out the areas along the route. Therefore, the combustor of hydrogen-fired gas turbine needs to be improved to achieve low NOx emissions and stable combustion, particularly focusing on preventing flashback.

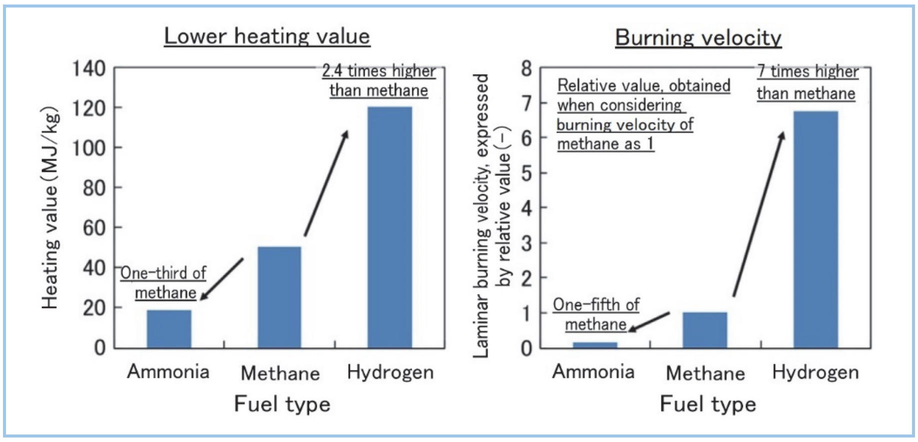


Figure 3 Comparison of methane, hydrogen and ammonia in terms of lower heating values and burning velocity

On the other hand, ammonia has a lower heating value that is about one-third lower than methane, and the burning velocity is lower nearly one-fifth. As the combustion tends to be unstable, the challenge lies in keeping the flame stable. As shown in **Table 2**, fuel NOx is produced in large quantities in the process of combustion, because ammonia contains nitrogen (N). The produced amount is larger by an order of magnitude than that of thermal NOx produced by the combustion of natural gas. As the mechanism of fuel NOx generation is different, an unconventional approach is needed to reduce such NOx.

Hydrogen and ammonia have thus dissimilar characteristics. The following sections describe the status in the development of MHI gas turbine combustors and combustion technologies, with which hydrogen or ammonia can be handled.

Table 2 NOx generation mechanisms

Fuel	NOx generation mechanism	Amount of NOx generated (with no measures taken)
Conventional fuel (e.g., LNG)	Nitrogen oxides are formed, as a result of nitrogen in the air being oxidized in the high-temperature combustion field (thermal NOx) N_2 (air) + O_2 → NOx *NOx is generated by the thermal decomposition of N_2	On a scale of several hundred ppm
Ammonia (NH_3)	Nitrogen oxides are formed, as a result of oxidation of the fuel (fuel NOx) NH_3 (fuel) + O_2 → N_2 + H_2O + NOx *NOx is generated by the chemical reaction of fuel	On a scale of several thousand ppm

2.2 Development of hydrogen-fired combustors

(1) Dry Low NOx (DLN) multi-nozzle combustor for hydrogen co-firing

A new hydrogen co-fired combustor was developed based on the conventional DLN multi-nozzle combustor design, with the aim of preventing the risk of flashback from increasing due to hydrogen co-firing. **Figure 4** gives an outline. This premixed multi-nozzle combustor has eight premixed fuel nozzles and one pilot flame fuel nozzle in the center to stabilize combustion. Each nozzle is equipped with a swirler. The air passing through the swirler is mixed more uniformly with the fuel injected through the nozzle. There is a low flow velocity zone, which is located in the center of the swirling flow (hereafter referred to as the vortex core). It is believed that flashback occurs when the flame travels upstream through this vortex core. In the new combustor, therefore, air is injected from the tip of the nozzle to increase the flow velocity in the vortex core, thereby compensating for the low flow velocity therein to prevent flashback.

A single unit of this combustor was used to conduct a combustion test under the operating conditions (i.e., pressure and temperature) equivalent to a large gas turbine with the turbine inlet temperature of the 1,600°C class (hereafter referred to as the actual-pressure test) (Figure 4, left below). No flashback occurred at the rated load, while the hydrogen co-firing ratio with natural gas was increased up to 30 vol%. The combustion was stable without a marked rise in combustion instability. NOx emissions were below the permissible level. These results support the feasibility of operation in actual units.

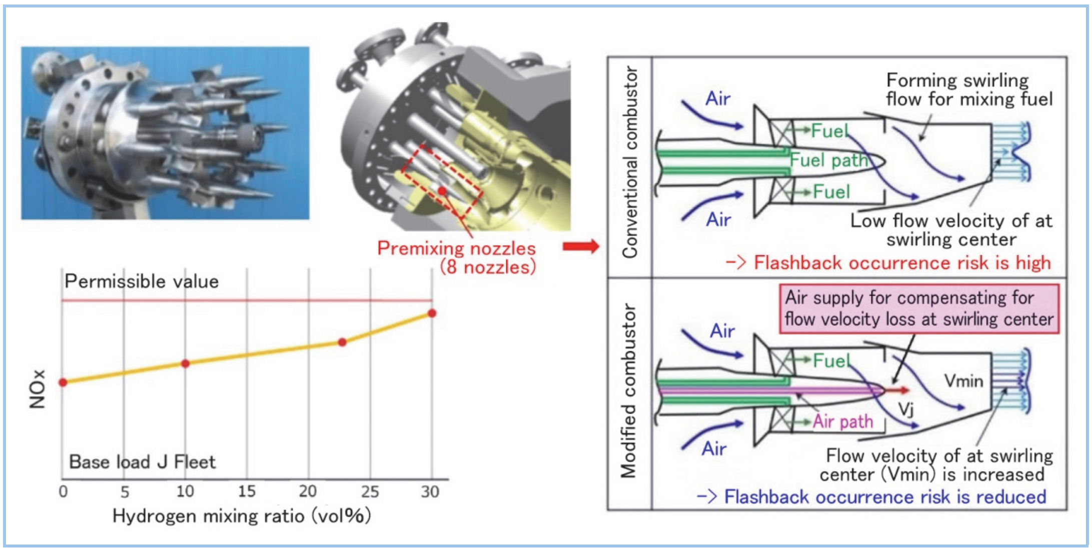


Figure 4 Hydrogen co-fired combustor and NOx levels at 30 vol% hydrogen co-firing testing

Moreover, as a measure to achieve a higher co-firing ratio of hydrogen, the pilot flame fuel nozzle in the center of the combustor employs diffusion combustion, which does not entail the risk of flashback, as shown in **Figure 5**. Our plan is to further improve this design for enabling hydrogen single-firing. It is possible to increase the average hydrogen co-firing ratio for the entire combustor up to 50 vol% by feeding the fuel blended with 30 vol% hydrogen through the eight premixed nozzles. Although NOx production may increase in the diffusion combustion zone, it can be prevented by injecting water therein. The actual-pressure test has demonstrated the operability of this combustor with NOx emissions below the permissible level and the stable operation without flashback or marked rise in combustion instability. The continuous improvement for a higher hydrogen co-firing ratio is still necessary. The development is in progress toward the validation with an actual unit.

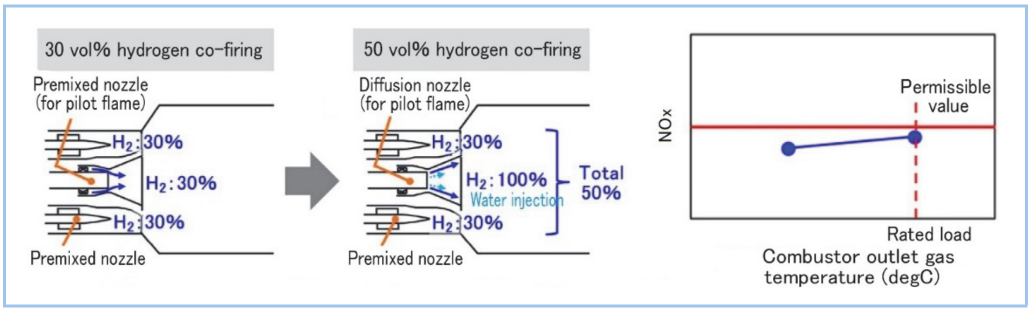


Figure 5 Improvement to achieve higher hydrogen co-firing ratio and NOx levels at 50 vol% hydrogen co-firing

(2) Multi-cluster combustor for hydrogen single-firing

As the hydrogen concentration becomes higher, the risk of flashback gets higher. The resistance to flashback is considered higher, if the mixing distance can be shortened by mixing air and hydrogen at a higher flow velocity on a smaller scale, rather than the multi-nozzle system described in the earlier section in which air and hydrogen are mixed together using a swirling flow at a relatively low velocity in a large space. **Figure 6** shows a multi-cluster combustor for hydrogen single-firing, which is currently in development. There are many holes (premixing tubes) in the combustor, in which air and fuel are rapidly mixed. Formation of many dispersed flames can also reduce NOx production.

In order to verify the combustion concept mentioned above and the combustibility, a combustion test was conducted under the pressure conditions equivalent to the actual unit using an elemental burner, which is a part taken from the multi-cluster nozzle. **Figure 7** shows the combustion test equipment and the images of the flame during combustion. Hydrogen burns with a flame with almost no emission of visible light; luminescence particular to hydrogen occurs in the ultraviolet range. The ultraviolet imaging shows the uniform formation of stable flames a little away from the outlets of single premixing tubes in the burner. The test has confirmed the occurrence of no flashback and stable combustion under the designed test conditions.

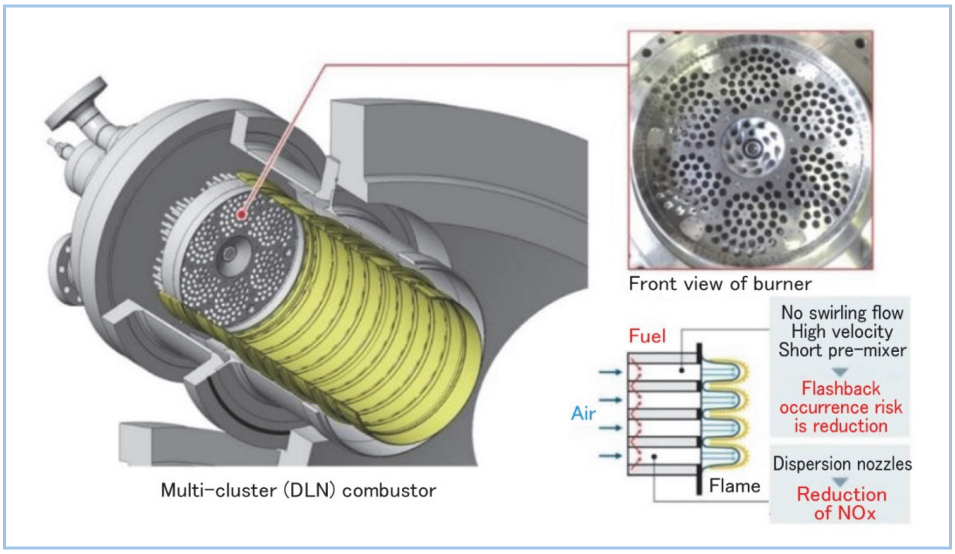


Figure 6 Multi-cluster combustor for hydrogen single-firing

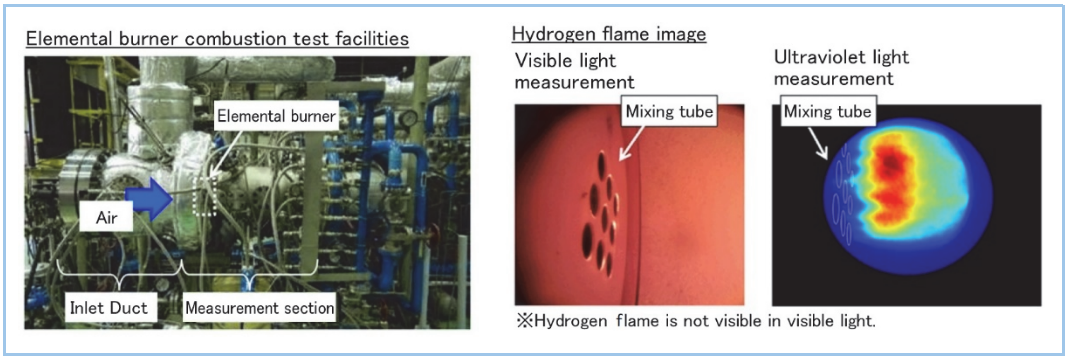


Figure 7 Elemental burner combustion test facility with a multi-cluster burner and hydrogen flames image

Furthermore, for small-to-middle class H-25 gas turbines, a full-scale actual-pressure test was conducted using a multi-cluster combustor for hydrogen single-firing, which is currently in development. In this test, the load was increased under the simulated operating conditions (i.e., temperature and flow rate) of an actual unit in which hydrogen is single fired. Without any flashback or sudden rise in combustion instability, the combustion temperature reached the level equivalent to the rated load of the actual unit. **Figure 8** shows the NOx measurements with increasing load. While attempting to further reduce NOx, the development will continue toward the validation with an actual unit.

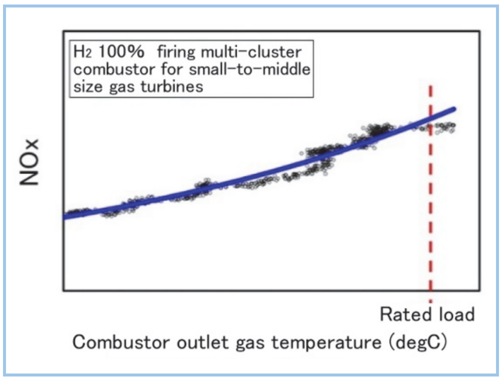


Figure 8 NOx levels at hydrogen single-firing

These findings are also used as the basis for the design of multi-cluster combustors for large gas turbines. An actual-pressure combustion test with one full-scale combustor is underway with a view to the validation for an actual unit in the future. The validation test will be conducted using the actual-pressure combustion test facility at MHI's Takasago Machinery Works, as in the case of the hydrogen co-firing test as shown in **Figure 9**. Hydrogen fuel, which is required in large quantities for the hydrogen single-firing test, will be supplied from the hydrogen storage facility newly installed at the Hydrogen Park Takasago (described later) on the premises of Takasago Machinery Works. In the actual-pressure combustion test, the small-to-middle class H-25 gas turbine drives the air compressor, which supplies air for combustion. This gas turbine will be used as the test unit, when hydrogen single-firing in a small-to-middle gas turbine is verified.

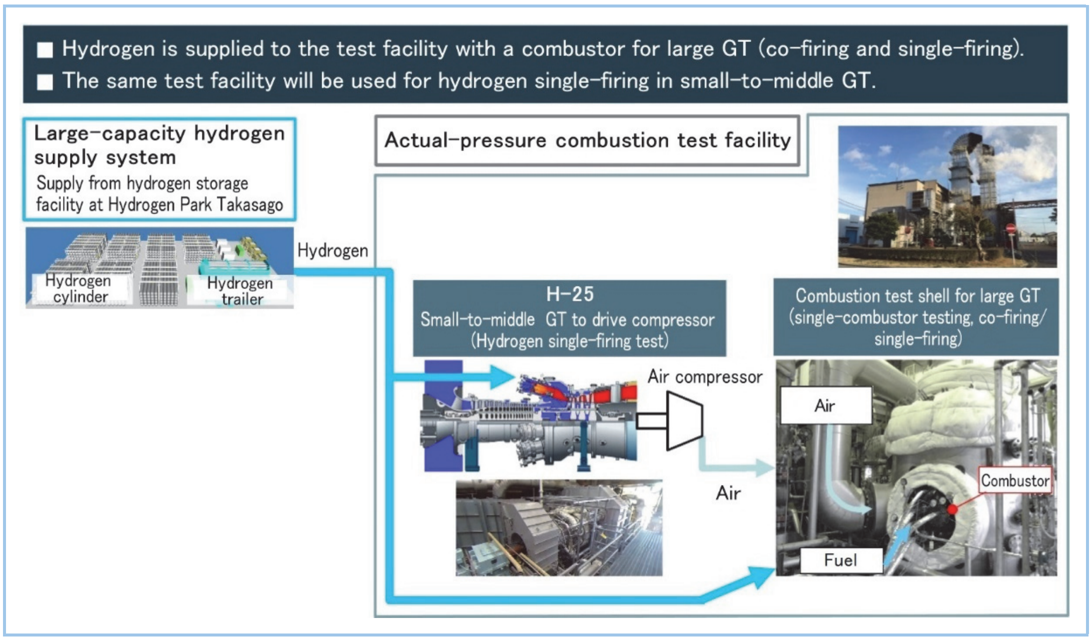


Figure 9 Actual-pressure combustion test facility with which hydrogen single-firing test will be conducted

2.3 Development status of ammonia-fired combustion systems

The technical challenges for burning ammonia as a fuel in gas turbines lie in keeping the flame stable in the combustor and controlling emissions of fuel NOx (i.e., NOx generated as a result of oxidation of nitrogen in ammonia fuel), as described in Section 2.1. MHI is looking into two types of GTCC systems using ammonia, as shown in **Figure 10**.

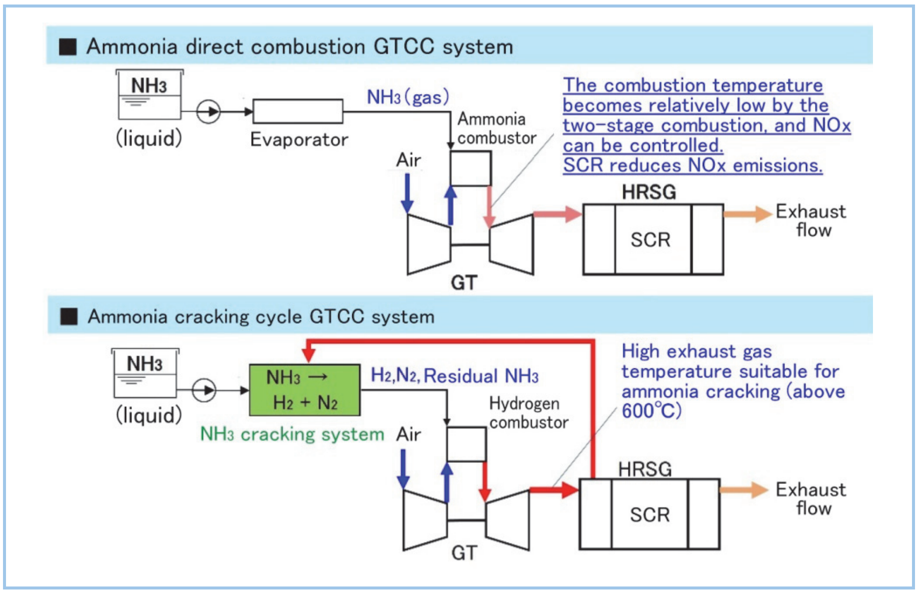


Figure 10 Ammonia-fired combustion systems

(1) Ammonia direct combustion GTCC system

In this gas turbine system, an ammonia combustor with less NOx emissions is combined with high-efficiency NOx removal equipment. For the combustor, a rich-lean two-stage combustion scheme based on the diffusion combustor is under consideration as shown in **Figure 11**. **Figure 12** shows a schematic representation of fuel NOx emission characteristics during ammonia combustion. There is a peak of fuel NOx generation in the neighborhood of a stoichiometric equivalence ratio of φ = 1 (at which stoichiometric complete combustion occurs between ammonia and air without excess or lack of either). In our rich-lean two-stage combustion scheme, however, ammonia fuel and air (primary combustion air) are burnt in the upstream side of the combustor in a fuel-rich state (φ ≥ 1 in the Rich Zone), before it is shifted to a lean combustion state (in the Lean Zone) by rapidly mixing with secondary combustion air. In this way, NOx generation is prevented.

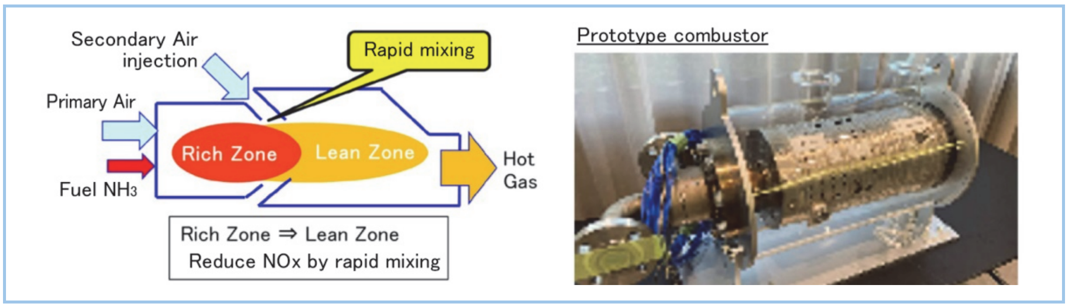


Figure 11 Ammonia combustor with a two-stage combustion scheme

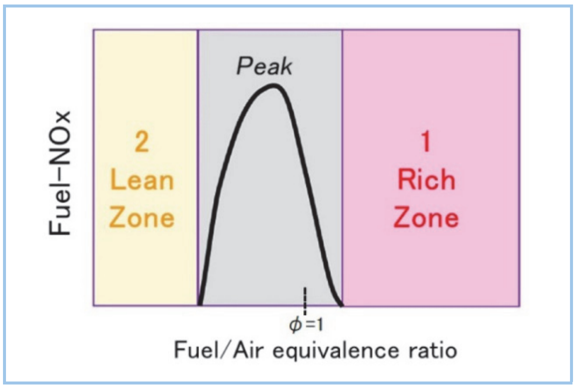


Figure 12 Fuel NOx emission characteristics during ammonia combustion

The development of this system will proceed first with targeting small-to-middle class H-25 gas turbine series. The ammonia combustion test facility at the Nagasaki District of MHI Research and Innovation Center is used to conduct an atmospheric pressure combustion test using a full-scale test combustor (one unit) for evaluation of the items such as flame stability, NOx emissions and changes in the properties when fuel is switched from hydrocarbons to ammonia. **Figure 13** shows the visualized images in the combustor, when the fuel (hydrocarbons or ammonia) is combusted. Hydrocarbons burn with a blue flame, while ammonia produces a distinctive orange flame. The actual-pressure combustion test facility with a high-pressure ammonia supply system at the Hitachi Works (Katsuta) will be used to conduct a combustion test under the pressure conditions equivalent to the actual unit. The development will be continued with the view to enabling operation in an actual unit and commercialization in or after 2025.

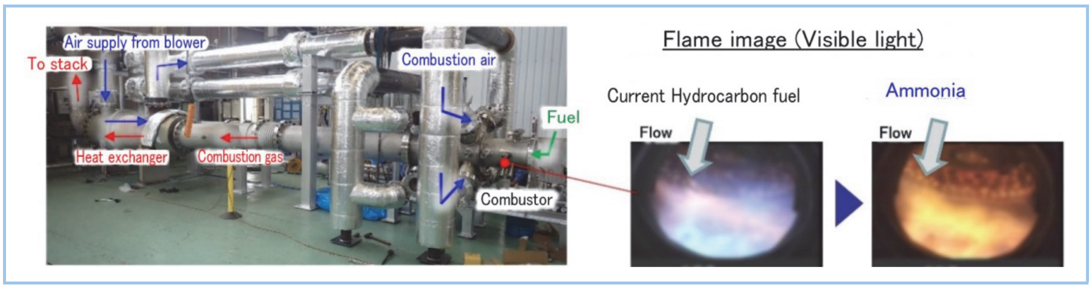


Figure 13 Atmospheric-pressure combustion test facility for ammonia and flame images in combustor

(2) Ammonia cracking GTCC system

In the ammonia cracking GTCC system, high-temperature waste heat from the gas turbine is used to decompose ammonia into hydrogen and nitrogen. The hydrogen is then burnt in the hydrogen co-fired combustor (Section 2.2 (1)) or the combustor for hydrogen single-firing under development (Section 2.2 (2)). The main component of the system is the ammonia cracking equipment. It is also considered usable as a system by which hydrogen is released from ammonia transported as a hydrogen carrier, to supply to other facilities/equipment using hydrogen. For the practical application, research will be continued considering the transfer of heat with a power generation system and the operability of the entire system as well.

3. Verification schedule

Actual gas turbines will be used for verification to enable early commercialization of hydrogen or ammonia-fired gas turbines. For the enhanced reliability of MHI products through verification using in-house facilities, the “Hydrogen Park Takasago” has been constructed on the premises of Takasago Machinery Works, to make it possible to perform the world’s first integrated technological validation from hydrogen production to power generation (**Figure 14**). The facility has been in operation since 2023.

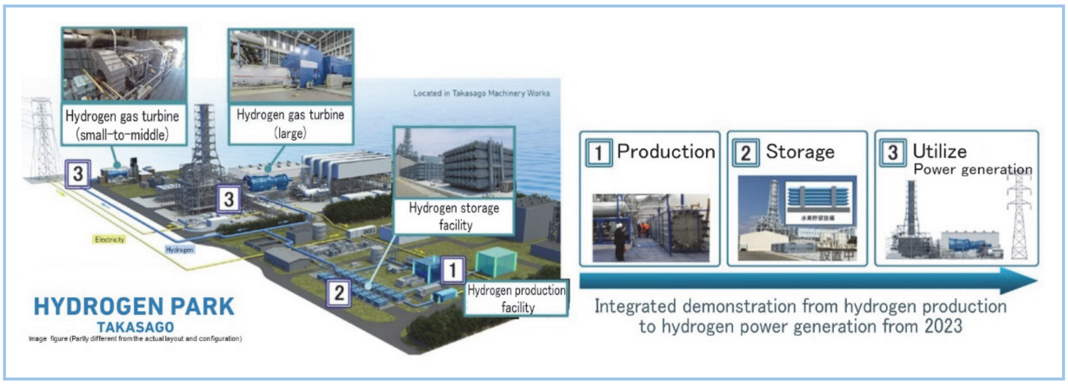


Figure 14 Hydrogen Park Takasago

Figure 15 shows the schedule for actual-unit verification, together with the reduction timetable for CO_2 emissions from gas turbines. The single-combustor test has confirmed that the multi-nozzle combustor for large gas turbines with hydrogen co-firing can operate with blends of hydrogen fuel (up to 50 vol%). This satisfies the European CO_2 emission standards (the criteria by the EU taxonomy, which prescribe that gas thermal power plants with construction approval by the end of 2030 must not emit more CO_2 than 270 g/kWh[2]). From 2023, the validation of hydrogen co-firing in the actual unit is underway using the hydrogen supply system at the Hydrogen Park Takasago, with the aim of confirming the reliability for commercialization. Furthermore, hydrogen single-firing in an actual small-to-middle gas turbine will be validated using a multi-cluster combustor. Specifically, the H-25 gas turbine of the actual-pressure test facility (Figure 9) will be used as the test unit for validation. The commercial operation of hydrogen co-firing (30 vol%) including the U.S. project described later will be started in 2025. For large gas turbines, hydrogen single-firing is aimed to be verified by demonstration in 2030. Regarding ammonia firing, a demonstration will also be conducted on the small-to-middle class H-25 gas turbine to realize practical application.

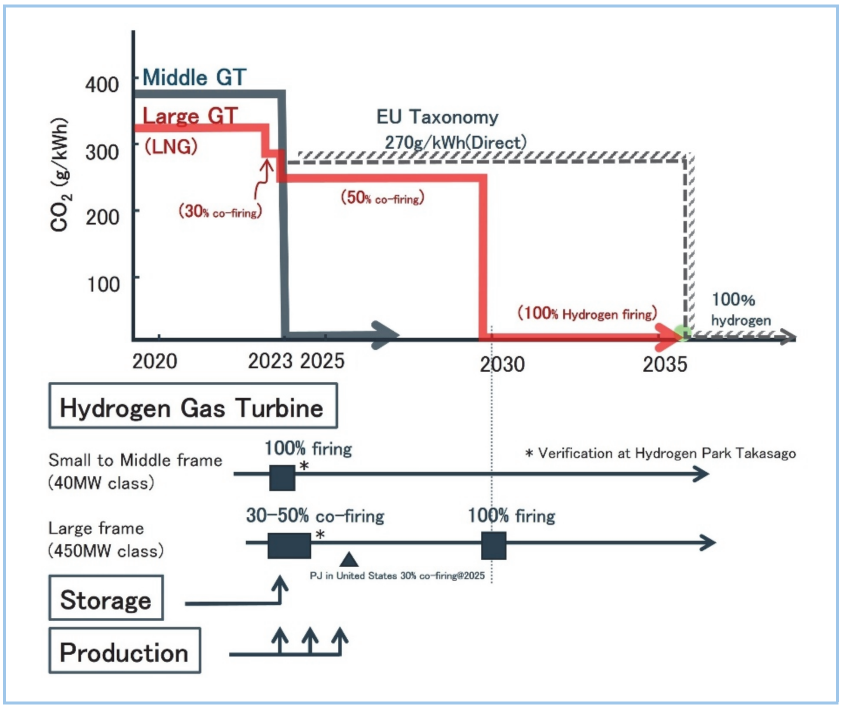


Figure 15　Schedule for actual-unit validation

4. Overseas projects for hydrogen or ammonia-fired gas turbines

In parallel with the scheduled demonstrations with an actual unit mentioned above, MHI takes part in business development in the leading regions for the utilization of hydrogen and ammonia in Japan as well as overseas, thereby working toward enabling the products to be practically applied while promoting collaboration with external parties. Some examples are given below.

4.1　Advanced Clean Energy Storage project in Utah, USA

Green hydrogen is produced using electricity from renewable energy sources found in abundance in the U.S. West Coast, before being stored in an underground rock salt cavern. When electricity is needed, the stored green hydrogen is taken out to feed the gas turbine for power generation. The generated electricity is then supplied widely in the states of California and Utah, aiming to stabilize the regional electricity supply and demand over a medium and long-term period. MHI received an order for a GTCC power generation facility consisting of two 840 MW class M501 JAC-type gas turbines as the core component, whose power generation plans involve 30 vol% hydrogen co-firing by 2025 and hydrogen single-firing by 2045. It is expected that power generation with 30 vol% hydrogen co-firing contributes to a reduction of up to 4.6 million tons of CO_2 emissions per year.

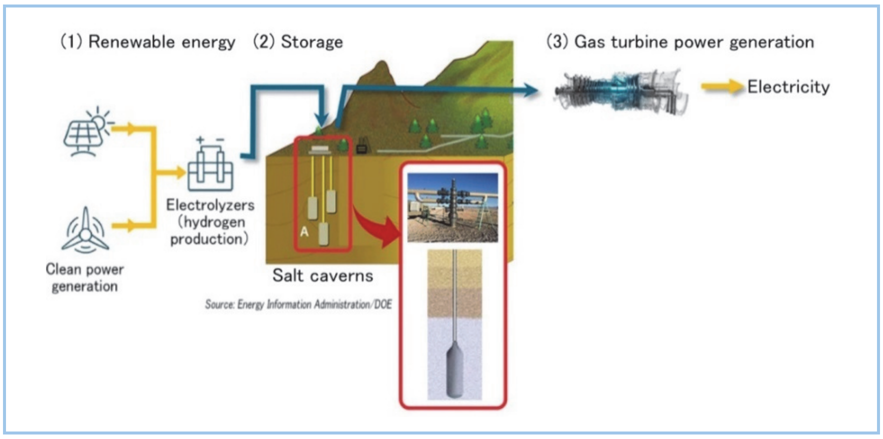


Figure 16　Advanced Clean Energy Storage project in Utah, USA

4.2 Hydrogen co-firing demonstration project at McDonough Atkinson Power Plant, USA

In 2022, as a hydrogen co-firing demonstration project at an existing gas turbine power plant, MHI Group together with Georgia Power, a U.S. electric utility, and the Electric Power Research Institute (EPRI) conducted a combustion verification test in which an MHI M501G-type natural gas-fired gas turbine (with a DLN multi-nozzle combustor) successfully operated on a blend of hydrogen and natural gas at the McDonough Atkinson Power Plant in Georgia, shown in **Figure 17**[3]. This project was the world's first demonstration of 20 vol% hydrogen co-firing in a large, high-efficiency GTCC power generation facility, and was the largest test of its kind in history. CO_2 emissions are reduced by about 7% from the level of natural gas firing, without affecting the turbine inlet temperature, emissions and maintenance intervals. This verification test has also demonstrated the following: the operation at a hydrogen blend ratio of 20 vol% throughout the full-load range of gas turbines while maintaining the same NOx level as natural gas-fired operation, and the improved combustion efficiency as a result of the decreased carbon monoxide (CO) emissions at partial load by co-firing hydrogen, thereby resulting in a 10% reduction (absolute value) in the minimum load at which the gas turbine can operate in compliance with the emission regulations.

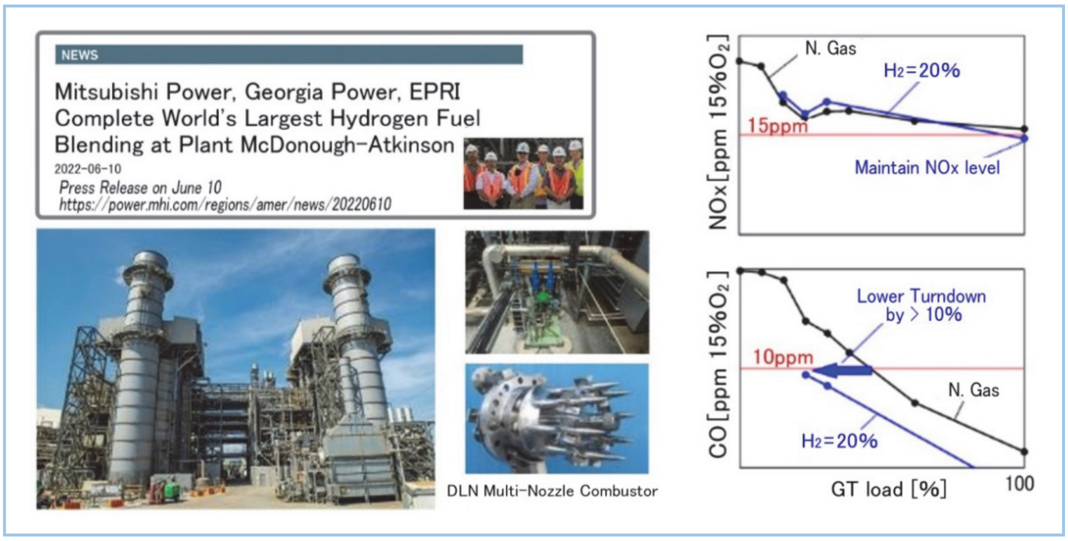


Figure 17 U.S. McDonough Atkinson Power Plant and the verification test results of combustion with a hydrogen blended fuel

4.3 Implementation plan of ammonia-fired gas turbines

Many countries are planning to introduce ammonia to existing thermal power plants. Although the application of ammonia co-firing in coal-fired boilers is ahead of the curve, there is also a growing worldwide demand for ammonia-fired gas turbines, as indicated by the implementation of the feasibility study (FS) for GTCC. MHI is also taking part.

5. Conclusion

Focusing on hydrogen or ammonia-fired gas turbines among MHI's projects for achievement of carbon neutrality, this report presents the development status of the main item (i.e., gas turbine combustors) and the schedule for validation.

Regarding the co-firing system of hydrogen and natural gas, the single-combustor test has demonstrated operability under the conditions in which 30 to 50 vol% hydrogen is co-fired. The development will be advanced to the next stage of actual-unit validation for commercialization. For the hydrogen single-firing system, actual-unit validation will be started with small-to-middle gas turbines. The development of gas turbine systems using ammonia will also be continued for commercialization. Expanding its product line-up of carbon-free power generation systems, MHI aims for decarbonization through energy transition by 2030.

Through cooperation with its partners across the world for the development and commercialization of hydrogen/ammonia-fired GTCCs that can contribute to CO_2 reduction, MHI continues to make efforts to achieve carbon neutrality as soon as possible.

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References

(1) Outlook for energy supply and demand in FY 2030 (related materials), Agency for Natural Resources and Energy,
https://www.enecho.meti.go.jp/category/others/basic_plan/pdf/20211022_03.pdf

(2) EU taxonomy: Complementary Climate Delegated Act to accelerate decarbonization,
https://finance.ec.europa.eu/publications/eu-taxonomy-complementary-climate-delegated-act-accelerate-decarbonisation_en

(3) Mitsubishi Power, Georgia Power, EPRI Complete World's Largest Hydrogen Fuel Blending at Plant McDonough-Atkinson, (2022) ,PRESS INFORMATION, Mitsubishi Heavy Industries, Ltd.,
https://power.mhi.com/regions/amer/news/20220610