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Next-generation ship development in Japan

New Engine Concepts & Systems

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ABSTRACT

In October 2020, Japan declared that it aims to achieve carbon neutrality by 2050, with the goal of reducing overall greenhouse gas emissions to zero by this year. As part of efforts to encourage companies and others to take on the positive challenge of realizing this goal, NEDO, New Energy and Industrial Technology Development Organization, Japan launched the "Green Innovation Fund Projects" initiative. It is currently working on 20 projects with a budget size of approximately 2.8 trillion yen. One of these projects is the "Development of Next Generation Ships," with a budget of 39.3 billion JPY (262 million USD) to be invested over a 10-year period until 2030.

To achieve carbon neutrality in the shipping sector, it is essential to move away from existing heavy fuel oil to new fuels such as hydrogen, ammonia, and clean methane from recycled carbon dioxide. It is also necessary to develop propulsion systems that utilize hydrogen and ammonia as fuels and reduce methane slip on vessels fueled by LNG or clean methane.

To achieve this goal, the project will develop engines, fuel tanks and fuel supply systems for ships using hydrogen and ammonia fuels and carry out demonstration operations using actual ships. Technology will also be developed to prevent methane slip, an important challenge for using LNG-fueled ships. The project ultimately aims to strengthen the international competitiveness of Japan's shipping-related industries, and promote social implementation in conjunction with the shipping industry.

This paper provides an overview of each of the projects listed below and their current research results.

1. Development of hydrogen-fueled ships

To achieve zero carbon emissions in the shipping industry, core technologies related to engines, fuel tanks, and fuel supply systems will be developed with the aim of realizing hydrogen-only combustion, and operational demonstrations of hydrogen fuel ships will be completed by 2030.

Theme1-1: Development of marine hydrogen engine and MHFS (Marine Hydrogen Fuel Tank and Fuel Supply System)

2. Development of ammonia-fueled ships

Core technologies related to engines, fuel tanks, and fuel supply systems will be developed that utilize a high ratio of ammonia fuel to reduce greenhouse gas emissions aiming to achieve commercial operation ahead of the previous target of 2028.

Theme2-1: Development of ships with ammonia fueled domestic engines

Theme2-2: Integrated project for development and social implementation of ammonia fueled ships

Theme2-3: Development of N2O reactor installed on ammonia-fueled ships

Theme2-4: Development of peripheral equipment for constructing a supply chain using ammonia-fueled ships

3. Preventing methane slip on LNG-fueled ships

To reduce methane emissions, which has high levels of greenhouse effect, technologies will be developed by 2026 to reduce “methane slip” levels on LNG-fueled ships by at least 60% using enhanced catalysts and engines.

Theme3-1: Development of methane slip reduction technology from LNG fueled ships by catalyst and engine modification

1 INTRODUCTION

In October 2020, Japan declared itself "carbon neutral by 2050," with the goal of balancing greenhouse gas (GHG) emissions and absorptions to an overall zero by 2050. As part of the policy to achieve this high goal, a 2 trillion JPY (Approximately 13.5 billion USD) fund was created in March 2021 at the New Energy and Industrial Technology Development Organization (NEDO), and the "Green Innovation (GI) Fund Project" was launched. The GI Fund Project provides continuous support for up to 10 years, from research and development and demonstration to social implementation, to companies and other entities that share ambitious and specific goals with the public and private sectors and address these goals as management issues. Currently, the budget has been increased to approximately 2.8 trillion JPY (18.7 billion USD), and 20 projects are undergoing research and development for which implementers have been selected through public solicitation [1]. One of these projects is the "Next-generation Ship Development," [2] a project related to the shipbuilding industry, which is being implemented with a support budget of approximately 39.3 billion JPY (262million USD).

As for developments related to carbon neutrality in the maritime sector, the International Maritime Organization's (IMO) 80th Marine Environment Protection Committee (MEPC) meeting in July 2023 unanimously adopted a new GHG reduction strategy, revising the 2018 IMO GHG Reduction Strategy [3]. The reduction strategy reinforces the current reduction targets for GHG reduction in international shipping, sets new guidelines for the reduction of total GHG emissions in 2030 and 2040, and outlines the concept and implementation schedule for specific mid-term measures to achieve these targets. Specifically, while maintaining the current "40% improvement in fuel efficiency by 2030 (compared to 2008 levels)," the committee set "zero GHG emissions by around 2050" and "5-10% use of zero-emission fuels, etc. by 2030," and established "20-30% reduction in total GHG emissions by 2030 (compared to 2008 levels)" and "2040 reduction target. emissions by 2030 (compared to 2008 levels)" and "70-80% reduction in GHG emissions by 2040 (compared to 2008 levels).

To achieve this goal, the project will develop engines, fuel tanks, and fuel supply systems for hydrogen- and ammonia-fueled ships and conduct demonstration operations using actual ships. The project will also develop technology to prevent methane slip (unburned CH_4 emissions), which is an important issue for LNG-fueled ships that run on liquefied natural gas (LNG), of which methane (CH_4) is a major component. Ultimately, the project aims to strengthen the international competitiveness of Japan's shipping-related industries and promote social implementation in cooperation with the shipping industry.

This paper presents an overview of each of the projects underway in the "Development of Next Generation Ships" and the results of current research.

2 GREEN INNOVATION FUND PROJECTS

2.1 Bacic polices for green innovation fund

The Ministry of Economy, Trade and Industry (METI) has established "Basic Policies" for the implementation of projects that applies commonly to each R&D field, including the target areas of support, mechanisms to maximize results, and implementation systems for the Fund projects. The main contents of the support are the 14 priority fields shown in Table 1 in the action plan of the Green Growth Strategy, or the major areas that have been indicated in the "Basic Policies for the Realization of GX" as the way forward. In addition, in order to maximize the results, the Fund Project is designed to require a strong commitment from the management of the companies that will be the main implementers to address the issue as a management challenge, and includes (1) the cancellation of the project or partial return of the commission fee in the event of insufficient efforts and (2) the introduction of incentive measures such as contingency funds in which the share of government expenses changes according to the degree of target achievement, etc.

Table 1. The 14 priority fields in the Green Growth Strategy.

Energy-related Industries	
1	Offshore Wind Power, Solar Power, Geothermal Power
2	Hydrogen and Fuel Ammonia
3	Next-generation Heat Energy
4	Nuclear Power
Transportation and manufacturing-related industries	
5	Automobiles and Storage Batteries
6	Semiconductors and Information and Communication
7	Shipping
8	Logistics, People Flows, and Civil Engineering Infrastructure
9	Food, Agriculture, Forestry, and Fisheries Industries
10	Aircraft
11	Carbon Recycling and Materials
Home and office - related industries	
12	Housing and Building and Next-generation Power Management
13	Resource Circulation
14	Lifestyle-related

NEDO is a national research and development corporation that creates innovation through the promotion of research and development necessary to realize a sustainable society. With the missions of “solving energy and global environmental problems” and “strengthening industrial technological capabilities,” NEDO aims to solve social issues as an “innovation accelerator” that develops and demonstrates high-risk innovative technologies and promotes social implementation of the results. Approximately 1,500 employees are engaged in its activities.

2.2 Lists of projects

Table 2 lists the 20 projects currently being implemented by the Green Innovation Fund. The projects related to the marine industry include “Large-scale hydrogen supply chain establishment,” “Hydrogen production through water electrolysis using power from renewables,” “Fuel ammonia supply chain establishment,” and “Development of technology for producing fuel using CO_2, etc.”

Table 2. Green Innovation Fund Projects.

Field of Green Power Promotion, etc.	
1	Cost Reductions for Offshore Wind Power Generation
2	Development of Next-Generation Solar Cells
3	Achieving Carbon Neutrality in Waste and Resource Circulation
Field of Energy Structure Transformation	
4	Large-scale Hydrogen Supply Chain Establishment
5	Hydrogen Production through Water Electrolysis Using Power from Renewables
6	Hydrogen Utilization in Iron and Steelmaking Processes
7	Fuel Ammonia Supply Chain Establishment
8	Development of Technology for Producing Raw Materials for Plastics Using CO_2 and Other Sources
9	Development of Technology for Producing Fuel Using CO_2, etc.
10	Development of Technology for Producing Concrete and Cement Using CO_2
11	Development of Technology for CO_2 Separation, Capture, etc.
Field of Industry Structure Transformation	
12	Next-Generation Storage Battery and Motor Development
13	Development of In-vehicle Computing and Simulation Technology for Energy Saving in Electric Vehicles
14	Smart Mobility Society Construction
15	Next-generation Digital Infrastructure Construction
16	Next-generation Aircraft Development
17	Next-generation Ship Development
18	Development of Negative Emissions Technologies in Agriculture, Forestry, and Fisheries Industries
19	Promotion of Carbon Recycling Using CO_2 from Biomanufacturing Technology as a Direct Raw Material
20	Decarbonization of thermal processes in manufacturing

The implementation of these projects is expected to expand the supply and reduce the cost of low-carbon fuels such as hydrogen and ammonia, and NEDO is working on each project in collaboration with other related projects, including information exchange.

2.3 Next-generation ship development

Compared to other means of transportation, ships are characterized by long-distance and mass transportation and are heavily dependent on heavy oil as a fuel. In recent years, LNG-fueled and methanol-fueled ships have been introduced in anticipation of mixed use with biofuels and a future shift to synthetic fuels, but the carbon content, supply and price of green fuels, and other concerns remain.

In order to achieve carbon neutrality in marine transportation, it is essential to switch from the existing fuel of heavy fuel oil to carbon-free gaseous fuels such as hydrogen, ammonia, and carbon-recycled methane, and it is necessary to develop hydrogen- and ammonia-fueled ships and marine equipment and to reduce methane slip on LNG (including carbon-recycled methane) fueled ships.

Since ships are generally used for a long period of time (more than 20 years), it is essential to start working on the environment for the introduction of zero-emission ships now in order to achieve carbon neutrality in 2050. Therefore, this project will develop hydrogen-fueled and ammonia-fueled ships (development of engines, fuel tanks, and fuel supply systems) for which technology maturity is low at present, and conduct onboard demonstrations. In addition, measures against methane slips, which is one of the issues for LNG-fueled ships, will be implemented. This will strengthen the international competitiveness of Japan's shipbuilding and marine industries, and the marine transport industry will also work together to implement the technology in society.

Currently, six themes are being addressed for three types of R&D items that are “Development of hydrogen fueled ships,” “Development of ammonia fueled ships,” and “Preventing methane slip on LNG fueled ships.” The implementation schedule for the six themes is shown in Figure 1. Each theme is being promoted while receiving technical and business advice from external committee members and receiving evaluations on whether to continue or discontinue the project.

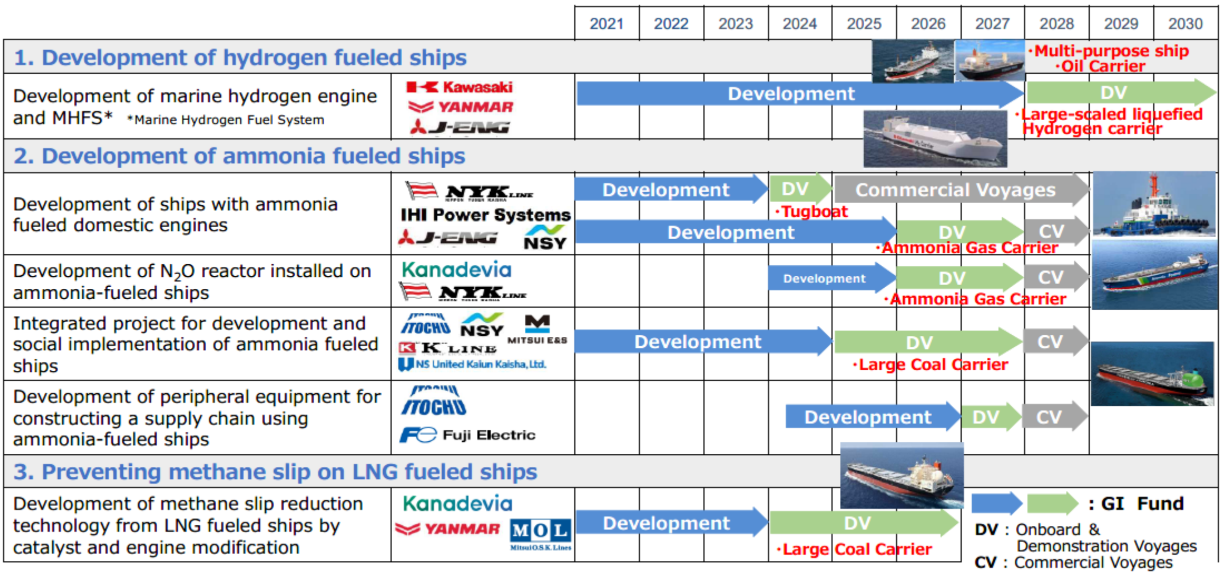

Figure 1. Development and full-scale test schedule for “Next-generation ship development” project.

3 DEVELOPMENT OF HYDROGEN FUELED SHIPS

Kawasaki Heavy Industries, Ltd. (KHI), Yanmar Power Technology Co., Ltd (YPT) and Japan Engine Corporation (J-ENG) established HyEng Corporation (HyEng), a new three-way joint venture, to jointly and efficiently solve common problems in handling hydrogen fuel and to contribute to the future spread of hydrogen fueled ships. As common tasks, HyEng is promoting the evaluation of hydrogen embrittlement, construction and maintenance of a demonstration test facility for hydrogen-fueled engines, and compliance with international rules on hydrogen fuel, while each company is developing hydrogen-fueled engines and KHI is developing marine hydrogen fuel tanks and fuel supply systems (MHFS). The goal is to complete the demonstration operation of hydrogen-fueled ships by 2030. The amount of the grant from NEDO is approximately 24.5 billion JPY.

HyEng conducted a material evaluation depending on the hydrogen concentration in the environment where the material would be used as an engine component. The Slow Strain Rate Technique (SSRT) was used to identify environments that have a large influence on hydrogen embrittlement, and the effect on fatigue limits was evaluated. The test is being conducted with the knowledge of universities, ClassNK, and other organizations to ensure that the evaluation is appropriate. Furthermore, a hydrogen engine onshore test facility has been constructed in the J-ENG plant, and demonstration operation of a multi-cylinder engine using hydrogen is scheduled to begin in FY2025. Figure 2 shows a photograph of the liquefied hydrogen tanks and other facilities at the onshore demonstration test facility.

Figure 2. Photograph of liquefied hydrogen tanks and other facilities in J-ENG plant.

3.1 Theme 1-1: Development of marine hydrogen engine and MHFS

3.1.1 Development of hydrogen-fueled engines

Hydrogen has a low minimum ignition energy, a high maximum combustion speed and the risk of abnormal combustion is high. In addition, it is necessary to develop combustion control and fuel injection technologies for engines to deal with problems specific to ships, such as large load fluctuations due to wave effects. In addition, it is necessary to develop technologies to solve problems inherent to hydrogen fuel (leakage prevention technologies for piping, joints, etc., and technologies to prevent material degradation due to hydrogen embrittlement, etc.).

Considering the time until the marine hydrogen fuel infrastructure is developed, we are working on the development of a hydrogen dual-fuel (DF) engine that can be used in combination with diesel fuel and has high redundancy, which is important in the marine market. In the hydrogen operation mode, heavy fuel oil, etc. is used as pilot fuel. In the future, our project plans to develop ignition technologies that does not use pilot fuel.

① Development of a medium-speed, 4-stroke hydrogen-fueled engine for propulsion

For medium-speed 4-stroke Otto-type hydrogen-fueled engines used as main engines for small and medium-sized ships and auxiliary engines for various types of ships, KHI will develop 2,000 to 3,600kW-class output DF engines. The 8-cylinder engine for land testing is the 8L30KG-HDF shown in Figure 3 with a cylinder diameter of 300mm and an output of 2,400kW in hydrogen mode.

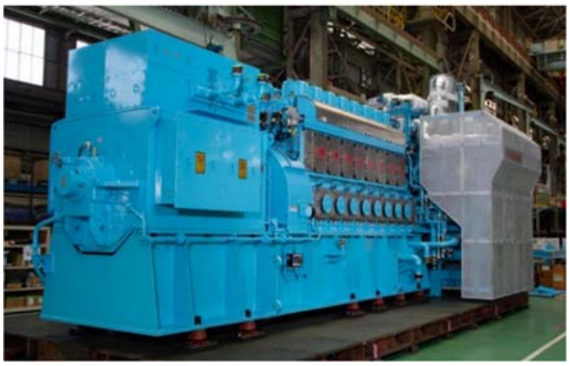

Figure 3. Photograph of KHI's 4-stroke hydrogen-fueled engine 8L30KG-HDF.

To suppress abnormal combustion, it is effective to keep the oxygen concentration in the engine low, and exhaust gas recirculation (EGR) was adopted and optimized. This can suppress the fast combustion characteristic of hydrogen fuel. In addition to EGR, the combustion chamber and control logic were optimized. As a result, the single-cylinder test engine achieved a hydrogen mixing ratio of 95%. The demonstration engine 8L30KG-HDF, which reflects these results, has been undergoing land testing in diesel mode since January 2025. Performance evaluation, durability evaluation, evaluation of each function in hydrogen fuel operation, and fuel switching test between hydrogen fuel and liquid fuel are underway.

After the development of 8L30KG-HDF, a 12-cylinder engine 12V30KG-HDF will be developed as the main propulsion generator for a 40,000m^3 liquefied hydrogen carrier shown in Figure 4 to be built by KHI for a long-term demonstration.

Figure 4. Conceptual drawing of a 40,000m^3 liquefied hydrogen carrier.

② Development of a medium-speed, 4-stroke hydrogen-fueled engine for use in auxiliary equipment

For medium-speed, 4-stroke Otto-type hydrogen-fueled engines used as auxiliary engines on various types of ships, YPT will develop two models with outputs of 800kW and 1,440kW engines. The 800kW output engine is the 6EY22DF-H shown in Figure 5, a 6-cylinder DF medium-speed engine with a 220mm bore diameter micro-piloted injection valve, and after onshore testing, YPT plans to demonstrate the engine on a domestic oil carrier from 2027. The single-cylinder test engine has achieved a hydrogen mixing ratio of more than 95%. Onshore trials of the actual engine, which will reflect the results of these tests, are scheduled to begin in May 2025.

The 1,440kW output engine is a spark-ignition, hydrogen-fired, high-speed engine that aims to achieve zero emissions for ships and space savings when installed in the engine room.

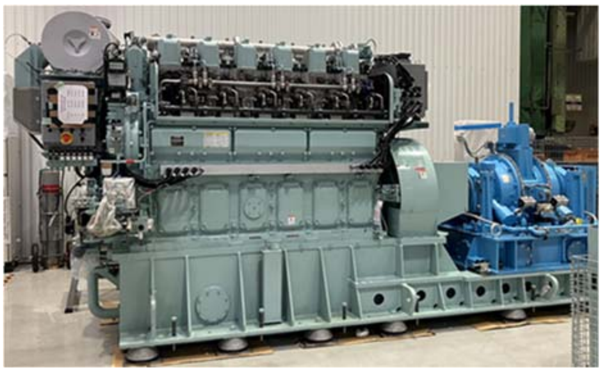

Figure 5. Photograph of YPT's 4-stroke hydrogen-fueled engine 6EY22DF-H.

③ Development of a medium-speed, 4-stroke hydrogen-fueled engine for use in auxiliary equipment

For 2-stroke engines used as main engines for large ships, J-ENG is aiming to develop the world's first 5,000kW-class output low-speed, two-stroke, diesel-cycle (high-pressure gaseous hydrogen injection) hydrogen-fueled engine. The engine under development is the UEC35LSGH shown in Figure 6 with a cylinder diameter of 350mm and a piston stroke of 1.55m. After about one year of onshore verification operation of the actual engine in 2026, the engine is scheduled to be operated for demonstration using a multi-purpose ship. The engine is designed as a dual-fuel engine with both heavy fuel oil and hydrogen fuel supply systems. In the hydrogen-fueled operation mode, the engine is a co-combustion engine that uses heavy fuel oil as the pilot fuel. In the future, J-ENG plans to develop a 100% hydrogen combustion engine without pilot fuel, aiming for an ultimate zero-emission engine without any GHG emissions.

The use of highly flammable hydrogen as an engine fuel requires the prevention of abnormal combustion. However, it is known that the frequency of excessive premature ignition is extremely high in large, low-speed, two-stroke engines with low rpm and large cylinder diameters. The UEC35LSGH uses a diesel cycle system (diffusion combustion) in which high-pressure (approximately 30MPa) hydrogen is injected directly into the cylinder near the top dead center to prevent excessive premature ignition and to control the ignition timing in a stable manner. Compared with the Otto cycle system (premixed combustion), the diesel cycle system requires a high-pressure hydrogen supply, but has the advantage that the engine power ratio can be the same as that of a heavy fuel oil engine, so the engine size does not need to be enlarged.

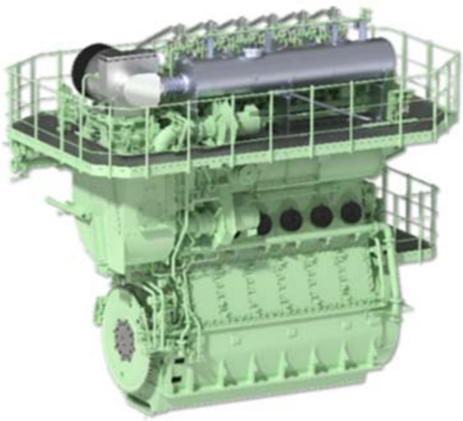

Figure 6. Image of J-ENG's 2-stroke hydrogen-fueled engine UEC35LSGH.

3.1.2 Development of hydrogen fuel tank and fuel supply system

Hydrogen, even in its liquefied state, has a volume approximately 4.5 times that of conventional fuel (Heavy fuel oil C) and is in a cryogenic state at -253°C. Therefore, when hydrogen is used as fuel for cargo ships, etc., it is necessary to develop a completely different concept of fuel tank for liquefied hydrogen, with space saving to minimize the impact on cargo space, temperature control in cryogenic conditions and measures against pressure fluctuations including BOG generation, and measures against cryogenic embrittlement and leakage to ensure safety. In particular, unlike cargo tanks, fuel tanks are prone to BOG generation due to the drop in liquid level caused by fuel consumption, so it is necessary to develop technologies for temperature and pressure management.

The hydrogen fuel supply system supplies fuel from the fuel tank to the engine, and consists of components such as a vaporizer, pump, and piping. Since measures against leakage and embrittlement are necessary to ensure safety, technology to supply fuel at optimal pressure and speed to improve engine efficiency will be established. The development of the fuel tanks and fuel supply system is being carried out with attention to the fact that the hull form and equipment layout will need to be changed from that of conventional fuel tankers when the fuel tanks and fuel supply system are installed on board.

There are two types of MHFS developed by KHI: a small MHFS (1MW class, 1MPa low-pressure supply, 30m^3 tank capacity) for medium- and high-speed 4-stroke hydrogen engines for onboard power generation developed by KHI and YPT, and a large MHFS (3MW class, 30MPa high-pressure supply, 200m^3 tank capacity) for low-speed 2-stroke hydrogen engines for ship propulsion developed by J-ENG. The MHFSs will be operated with hydrogen fuel to verify safety and reliability, as well as functionality required for marine use, on actual ships. The social implementation of MHFS is planned for the promotion of liquefied hydrogen fuel in marine transportation and decarbonization of marine transportation. Table 3 shows the particulars of the small MHFS for 4-stroke hydrogen engines, and Figure 7 shows the external appearance of the unit.

Table 3. Particulars of small MHFS.

Unit size	40-feet container size
Liquid hydrogen fuel tank	approx. 30 m^3, approx. 1 MPaG, horizontal, cylindrical, vacuum multilayer insulation
Liquefied hydrogen filling volume	approx. 1,400kg
Hydrogen gas fuel supply system	Tank self-pressurization method approx. 0.7MPaG, approx. 100kg/h at normal pressure

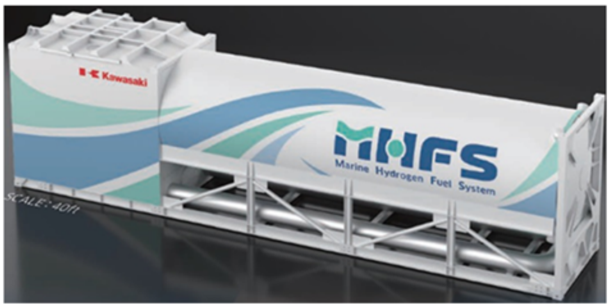

Figure 7. General view of small MHFS unit.

4 DEVELOPMENT OF AMMONIA FUELED SHIPS

To use ammonia as fuel, it is necessary to develop injection and combustion control technologies for efficient combustion of flame-retardant ammonia and measures to reduce the generation and emission of nitrous oxide (N_2O), which has a greenhouse effect 265 times that of CO_2. In addition, the fuel supply system, which is also related to combustion control, must solve the problems inherent in ammonia fuel (safety measures, such as leakage prevention, are essential due to its corrosion resistance and toxicity). Ammonia has a boiling point of -33°C at ambient pressure, making it a gas at ambient temperature and pressure. Liquid ammonia is expected to be used in terms of fuel consumption and onboard space. A semi-cooled pressurized or cooled tank is envisioned for onboard liquid storage. Even in its liquid state, ammonia is approximately 2.7 times the volume of conventional fuel (heavy fuel oil C) and is toxic, so it is necessary to develop an innovative fuel tank that both saves space and ensures safety.

This R&D Item aims to develop elemental technologies related to DF engines with a high ammonia fuel usage ratio and fuel tank/fuel supply system to the extent that GHG reduction effects can be reasonably achieved, and is being undertaken by four consortia with the goal of commercial operation as early as possible by 2028. The amount of grant from NEDO is approximately 14.2 billion JPY.

4.1 Theme2-1: Development of ships with ammonia fueled domestic engines

With Nippon Yusen Kabushiki Kaisha (NYK) as a manager, NIHON SHIPYARD CO., LTD. (NSY), Japan Engine Corporation (J-ENG), and IHI Power Systems Co., Ltd. (IPS), ClassNK (NK) have formed a consortium to develop a 2-stroke ammonia-fueled engine for the main engines of large ships and a 4-stroke ammonia-fueled engine for the main engines of small and medium-sized ships and auxiliary engines for various types of ships. For each of these engines, this consortium will develop an engine that uses as high a ratio of ammonia fuel as possible, and after conducting onshore tests, it will conduct an onboard demonstration using the ammonia-fueled tugboat and an ammonia-fueled medium-size ammonia gas carrier (AF-MGC). The world's first ammonia-fueled tugboat "SAKIGAKE" shown in Figure 8, which was designed for commercial use, completed a three-month demonstration voyage in November 2024, engaged in towing operations in Tokyo Bay. The 40,000m^3 type AF-MGC shown in Figure 9, which is scheduled to be operated by NYK, has been designed to overcome the toxicity that is the biggest challenge in the use of ammonia marine fuel, and is under development for completion in November 2026.

Figure 8. Photograph of the world's first ammonia-fueled tugboat "SAKIGAKE" operated by NYK.

Figure 9. Conceptual drawing of the 40,000m^3 type ammonia-fueled medium-size ammonia gas carrier (AF-MGC) operated by NYK.

① Development of a 4-stroke ammonia-fueled engine for propulsion and auxiliary use

The appearance of the IPS-developed 6-cylinder engine 6L28ADF (cylinder diameter 280mm, output 1,618kW) is shown in Figure 10. The engine is an ammonia-fueled Otto cycle type, in which ammonia is fed into the intake pipe to form a mixture with air, compressed by a piston, and ignited by pilot fuel oil near the top dead center. The ammonia fuel share ratio of 90% (10% of the heat value is pilot fuel oil) was achieved in both land tests and sea tests using the ammonia-fueled tugboat "SAKIGAKE". The emissions of N_2O and unburned ammonia, which were pending, were reduced by the exhaust gas after-treatment system to almost zero, and a GHG reduction ratio of 85% or more was achieved at maximum compared to heavy fuel oil. Figure 11 shows the fuel share ratio at various loads in the onshore test, and Figure 12 shows the GHG reduction ratio compared to diesel engine. The pending N_2O and unburned ammonia were reduced by the exhaust gas after-treatment system to almost zero, and a GHG reduction rate of more than 85% was achieved compared to that of heavy fuel oil. In offshore tests, IPS has confirmed that the engine has the performance required for tugboats to follow load fluctuations and that there is no ammonia leakage during operation and after shutdown. IPS is also developing a 6-cylinder DF engine 6L25ADF (bore diameter 250 mm, output 1,300 kW) for the generator of the ammonia-fueled ammonia carrier AF-MGC, and plans to complete land-based tests and ship it in mid-2025.

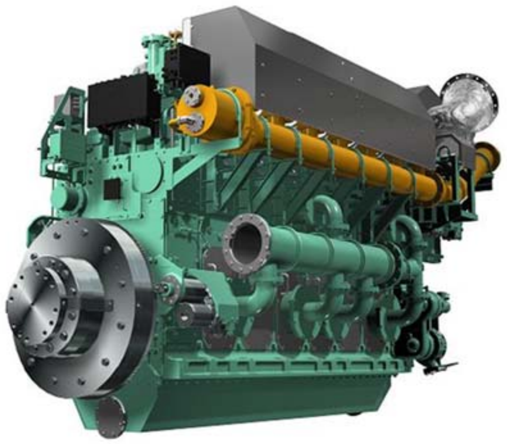

Figure 10. Photograph of IPS's 4-stroke ammonia-fueled engine 6L28ADF.

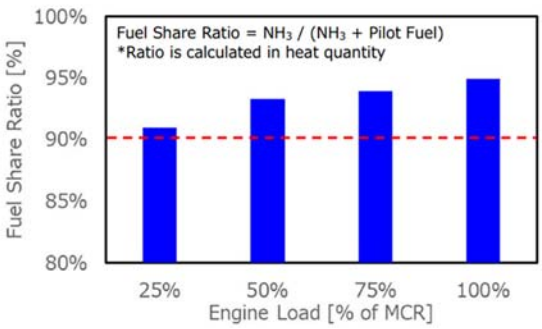

Figure 11. Ammonia fuel share ratio at various loads.

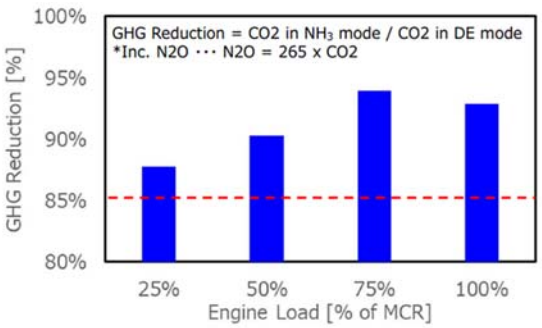

Figure 12. GHG reduction rate at various loads in ammonia mode.

② **Development of 2-stroke ammonia-fueled engine for propulsion**

The 7-cylinder ammonia-fueled DF engine 7UEC50LSJA (cylinder diameter 500mm, output approx. 8,000kW) under development at J-ENG uses the diesel cycle method because it has a low speed and allows time for liquid ammonia to be injected and evaporate in the cylinder. In the diesel cycle, fuel is injected at high pressure into air near the top dead center, which is compressed by the piston to a high temperature. This method has the advantage of reducing the slip of unburned ammonia while increasing the fuel share ratio of even flame-retardant ammonia. Furthermore, the application of stratified injection technology [4] in this engine is expected to promote the ignition of ammonia fuel and combustion after the fuel injection is completed, thereby reducing the formation of unburned ammonia and N_2O.

J-ENG started the world's first ammonia co-firing operation of a large low-speed 2-stroke engine in May 2023 and completed in September 2024. Figure 13 shows the appearance of the ammonia fuel test engine and ammonia fuel supply facility. The engine was operated under various conditions to optimize various operating parameters, determine fuel consumption and exhaust gas performance, and demonstrate safety, and engine performance up to 95% co-firing rate was confirmed The GHG reduction rate is approximately 90%.

Figure 13. Ammonia-fueled test engine, ammonia fuel supply facilities.

The UEC50LSJA engine shown in Figure 14, the first ammonia-fueled engine for actual ships, is a dual-fuel engine equipped with both fuel oil and ammonia fuel supply systems. Using the full-scale ammonia-fueled engine onshore demonstration test facility constructed in the J-ENG plant, the engine is planned to undergo onshore verification operation for about 6 months in 2025, followed by completion in September of the same year. The ammonia-fueled engine will then be installed in the AF-MGC for demonstration operations starting in FY2026. Figure 15 shows a photograph of the ammonia fuel tanks and other equipment at the onshore verification test facility.

Figure 14. Image of J-ENG's 2-stroke ammonia-fueled engine UEC50LSJA.

Figure 15. Photograph of the ammonia tanks and other facilities in the J-ENG plant.

4.2 Theme 2-2: Integrated project for development and social implementation of ammonia fueled ships

With ITOCHU Corporation (ITC), a general trading company, as a manager, NIHON SHIPYARD CO.,LTD. (NSY), MITSUI E&S Co., Ltd. (MES), Kawasaki Kisen Kaisha, Ltd. (“K”LINE), and NS United Kaiun Kaisha, Ltd. (NSU) have formed a consortium to promote an integrated project covering the entire range of “development,” “ownership and operation,” “fuel production,” and “fuel supply base development” of ammonia-fueled ships as shown in Figure 16 in order to realize early social implementation. The project is being carried out as an integrated project covering the entire range of development, ownership, operation, fuel production, and fuel supply bases. In addition to Singapore, ITC is aiming to establish multiple fuel supply bases.

In July 2021, the ITC, together with 34 organizations and companies, launched the Council as a forum to hear various opinions, including those on safety, when considering ammonia as a fuel at the request of shippers. The Council held a series of sessions in the form of lectures by domestic and foreign experts on the following four topics: (1) safety of ammonia-fueled ships, (2) safety of ammonia bunkering, (3) ammonia fuel specifications, and (4) net CO_2 emissions during ammonia production. Furthermore, regarding the safety of ammonia bunkering, a “Port Council” was established in March 2022 with major port authorities in Singapore and Europe to exchange opinions, and items considered necessary for the design and development of ammonia-fueled and ammonia-bunkering ships were identified as “Key Factors”, Opinions were exchanged.

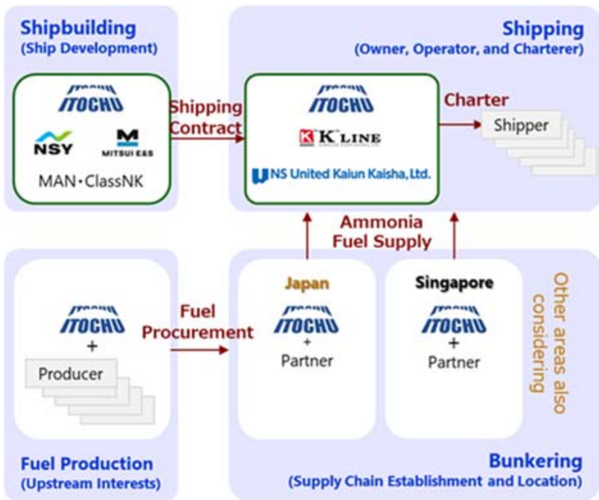

Figure 16. Correlation of integrated projects.

MES has started ammonia-fueled test operation of the world's first ammonia-fired large low-speed dual-fuel commercial engine 7S60ME-C10.5-LGIA-HPSCR (7-cylinders, cylinder diameter 600 mm, rated output 17,430kW x 105 min^{-1}) in February 2025. This engine is a large, low-speed, two-cycle commercial engine that is being developed based on the results of single-cylinder ammonia-fueled test runs conducted on a test engine of MAN Energy Solutions, the licensor of the project. In this project, peripheral systems other than the engine, such as an ammonia fuel supply system, are being developed to demonstrate safety and performance. The engine and peripheral systems will be installed in a ammonia-fired bulk carrier to be built in NSY.

4.3 Theme 2-3: Development of N_2O reactor installed on ammonia fueled ships

One of the challenges of ammonia is the treatment of N_2O generated during combustion. N_2O has a global warming potential 265 times greater than CO_2, and emissions of 100ppm offset the fuel conversion effect. Kanadevia Corporation (KVC) and Nippon Yusen Kabushiki Kaisha (NYK) have formed a consortium to develop an N_2O reactor for ammonia-fueled ships, which are expected to be widely used in the future.

The N_2O reactor developed by KVC in this project consists of an N_2O decomposition catalyst and a ship to contain the catalyst. The N_2O decomposition catalyst under development will be tested in the laboratory to improve its decomposition performance and durability, and then a method for catalyst mass production will be established. The N_2O reactor will be tested on land using the 2-stroke ammonia engine being developed by J-ENG, and then demonstrated on board an AFMGC operated by NYK as described in section 4.1.

4.4 Theme 2-4: Development of peripheral equipment for constructing a supply chain using ammonia fueled ships

The practical use of ammonia-fueled ships requires the establishment of a fuel supply system that includes the procurement of marine fuel, its storage at ports, and the securing of bunkering ships that will be responsible for fuel supply. In this process, it is important to establish safe bunkering operations. It is essential to take such measures as high-sensitivity (5 ppm or less) confirmation of the absence of residual ammonia in the pipe when disconnecting the bunkering hose after unloading, instantaneous leak detection in the event of an ammonia leak, and recovery and treatment of mixed gas generated by ammonia treatment in the hose before disconnecting the hose.

ITOCHU Corporation (ITC) and Fuji Electric Co., Ltd. (FE) have formed a consortium to develop highly sensitive measurement equipment capable of detecting ammonia concentrations as low as 5ppm, a trace ammonia leak detection system, and recovery and recycling technology for the advanced safety measures required for the expanded use of ammonia when constructing the supply chain for ammonia fueled ships. This consortium is working on the development of high-sensitivity measurement equipment, leak detection systems, and recovery/recycling technologies that can detect even ammonia concentrations as low as 5ppm. The technology and equipment developed by FE are planned to be tested on land and then demonstrated on a actual ship using a bulk carrier as described in section 4.2. The consortium also aims to adopt and supply the developed equipment to other consortiums that are developing ammonia-fueled ships in this project.

5 PREVENTING METHANE SLIP ON LNG FUELED SHIPS

5.1 Theme 3-1: Development of methane slip reduction technology from LNG fueled ships by catalyst and engine modification

LNG-fueled ships are being commercialized ahead of hydrogen- and ammonia-fueled ships, but methane-slip issues must be overcome to achieve high GHG reductions. Methane (CH_4) has 28 times the greenhouse effect of CO_2, but fuel consumption regulations are insufficient to motivate companies to reduce CH_4 slip, and the IMO is currently discussing international standards for CH_4 slip.

With Kanadevia Corporation (KVC) as a manager, YANMAR POWER TECHNOLOGY Co., Ltd. (YPT) and Mitsui O.S.K. Lines, Ltd. (MOL) have formed a consortium to develop technologies to reduce CH_4 slip in order to reduce greenhouse methane emissions. With the goal is to achieve a CH_4 slip reduction rate of at least 70% for LNG-fueled ships by 2026, the plan is to minimize the total CH_4 slip from LNG-fueled marine DF engines by combining the modification of a YPT's 6-cylinder engine 6EY22ALDF (Cylinder diameter 220mm, output 800kW) to reduce CH_4 slip and a KVC's methane oxidation catalyst as an after-treatment device. The grant from NEDO is 600 million JPY.

Moderate lean burn and exhaust gas recirculation (EGR) techniques were applied to the engine modifications. As the first step of this project, combustion experiments were conducted using a single-cylinder engine to investigate the effects of moderate lean-burn and EGR on CH_4 missions from an LNG-fueled engine. Next, the EGR and CH_4 oxidation catalysts were evaluated in a land-based bench test using a full-scale engine to confirm their effectiveness in reducing CH_4 slip. Furthermore, EGR was introduced into the full-scale engine and a new engine control technique was introduced to ensure stable operation. A system diagram of the low-pressure EGR and CH_4 oxidation catalyst system installed in the engine is shown in Figure 17.

Total CH_4 emission rates in land-based tests for engine modification with EGR and CH_4 oxidation catalyst at various engine load conditions are shown in Figure 18. Exhaust gases with reduced CH_4 concentrations due to the engine modification pass through an additional CH_4 oxidation catalyst to reduce CH_4 slip at the system outlet. The total system CH_4 slip reduction reached 97-99%. The CH_4 slip reduction before and after the CH_4 oxidation catalyst is 93.8% at 100% load. The GHG emission rates are shown in Figure 19. The synergistic effect of the high CH_4 slip reduction rate at the system exit (engine improvement + CH_4 oxidation catalyst) and improved fuel economy in the practical load range resulted in a 16% reduction in GHG emissions at 100% load and a 61% reduction at 25% load compared to the original engine.

The system is being tested on the LNG-fueled coal carrier “REIMEI” shown in Figure 20, which MOL has been operating since the fall of 2024, and is being evaluated under actual onboard operating conditions.

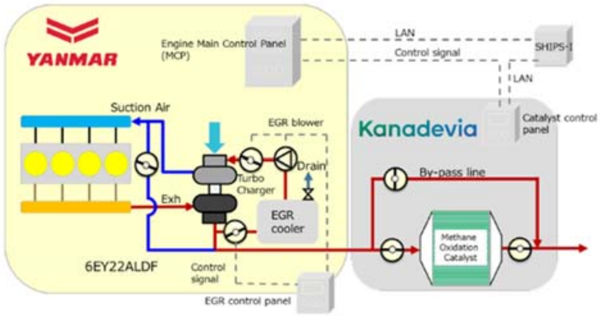

Figure 17. System diagram of low-pressure EGR and CH_4 oxidation catalyst system.

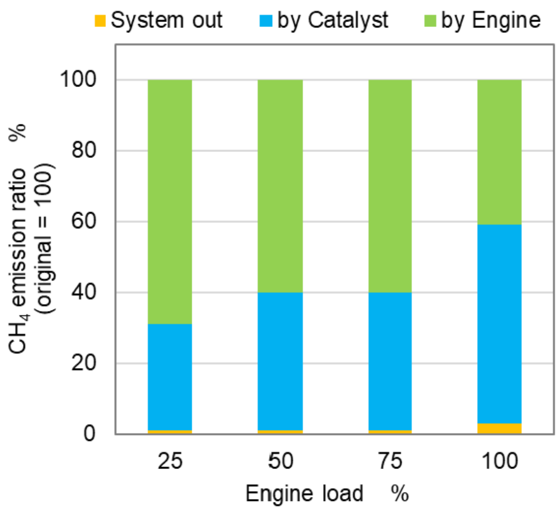

Figure 18. Total CH_4 slip reduction at various at various engine load conditions.

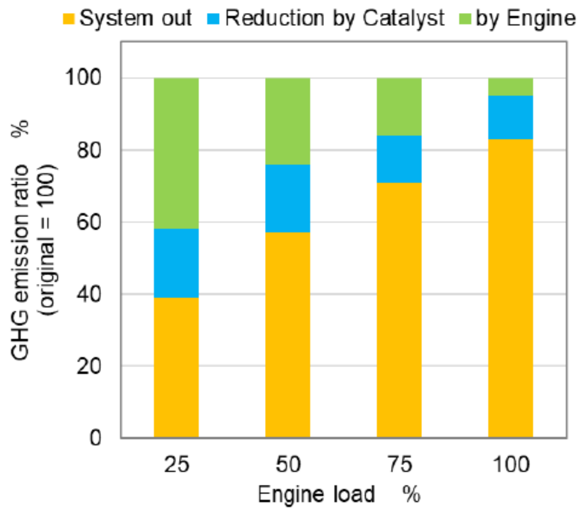

Figure 19. GHG emission ratio at various engine load conditions.

Figure 20. Photograph of the LNG-fueled coal carrier “REIMEI” operated by MOL.

6 CONCLUSIONS

Currently, the three R&D items (Development of hydrogen fueled ships, Development of ammonia fueled ships and Preventing methane slip on LNG fueled ships) under “Next-generation ship development” are progressing as planned without major problems. As the project progresses, common issues such as safety measures, increase in construction cost, and establishment of fuel supply chain are becoming clear. NEDO will continue to play its role as an “innovation accelerator” in close cooperation with related ministries (Ministry of Land, Infrastructure, Transport and Tourism, Ministry of Economy, Trade and Industry), related businesses, and maritime associations so that the next-generation ships under development will be implemented in society and contribute to the realization of carbon neutrality by 2050.

7 ACKNOWLEDGMENTS

The Ministry of Land, Infrastructure, Transport and Tourism (MLIT) took the lead in planning the Next-generation ship development," one of the "Green Innovation Fund Project" initiated by the Ministry of Economy, Trade and Industry (METI). The project implementation system incorporates the knowledge of outside experts, and a highly transparent and effective governance system has been established with close cooperation among the organizations involved. We would like to take this opportunity to thank all those involved in the project.

We would also like to express our deepest gratitude to the following organizations for their ongoing efforts in working on this project.

- **Development of hydrogen fueled ships**: Kawasaki Heavy Industries, Ltd., YANMAR POWER TECHNOLOGY Co., Ltd., Japan Engine Corporation
- **Development of ammonia fueled ships**: Nippon Yusen Kabushiki Kaisha, NIHON SHIPYARD CO., LTD., Japan Engine Corporation, IHI Power Systems Co., Ltd., ClassNK, ITOCHU Corporation, MITSUI E&S Co., Ltd., Kawasaki Kisen Kaisha, Ltd., NS United Kaiun Kaisha, Ltd., Kanadevia Corporation, Fuji Electric Co., Ltd.
- **Preventing methane slip on LNG fueled ships**: Kanadevia Corporation, YANMAR POWER TECHNOLOGY Co., Ltd., Mitsui O.S.K. Lines, Ltd.

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