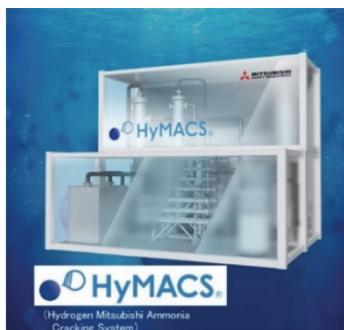


# Development of Ammonia Utilization Technology as Alternatives to Fossil Fuels : Middle-Scale, Decentralized HyMACS® (Hydrogen Mitsubishi Ammonia Cracking System)



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*Once a large-scale ammonia supply chain, such as one needed for ammonia-coal co-firing power generation, has been built, hydrogen demand in the surrounding areas is expected to increase for various applications. In early deployment phases, the hydrogen supply chain is likely to address small- to medium-scale demand across various industries including the chemical industry, as exemplified by the application as fuel in chemical plants.*

*Mitsubishi Heavy Industries, Ltd. focuses, as the primary target, on decentralized medium-scale hydrogen production by ammonia cracking, to tap into the demand for hydrogen with wide-ranging applications and latent demand. This report describes the progress in the development of Hydrogen Mitsubishi Ammonia Cracking System, highly thermally efficient ammonia-cracking and hydrogen-production technology that uses steam or flue gas as a heat source and applies a low-temperature, high-activity, non-precious-metal ammonia-cracking catalyst.*

## 1. Introduction

In the growth strategies to achieve the overall carbon neutrality of energy in Japan as well as the global community, ammonia is placed in the spotlight as a high-potential hydrogen carrier. There are already infrastructures for ammonia liquefaction and transport. Having a high density of hydrogen, it is advantageous to import low carbon hydrogen produced overseas by converting it into liquid ammonia from both sides of cost and implementation. **Figure 1** shows the superiority of liquid ammonia as a hydrogen carrier.

The technological development has so far centered around the centralized large-scale system of ammonia cracking. In the early stages of introducing clean hydrogen, however, demand is likely to arise from the decentralized medium-scale ammonia cracking system in the neighborhood of an ammonia receiving terminal. Distributing liquid ammonia, which is efficiently transportable, throughout the area with hydrogen demand requires no pipelines for supplying the produced hydrogen gas (i.e., no construction of large-scale infrastructure).

The steam/flue gas heating system can easily be incorporated into existing facilities. The use of a non-precious metal-based catalyst, which is highly active at low temperatures, ensures a stable supply. Combining these two advantageous features, Mitsubishi Heavy Industries, Ltd. (hereinafter referred to as MHI) intends to develop ammonia cracking equipment that can realize a compact design, lower operational cost and reduced risk of nitriding of metallic materials\*, thereby aiming to achieve the early establishment of decarbonization technologies and their implementation in society.

\* A phenomenon of a hard nitride layer being formed on the metallic material surface in a high-temperature environment containing ammonia gas, which causes embrittlement.

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Carrier	Liquefied H <sub>2</sub>	Methylcyclohexane	Ammonia	Methanation
Volume (relative to that of H <sub>2</sub> at normal pressure)	Approx. 1/800	Approx. 1/500	Approx. 1/1,300	Approx. 1/600
Conditions for liquefaction and toxicity	-253°C, atmospheric pressure Not toxic	Under ordinary temperature and pressure NB Toluene is toxic	-33°C, atmospheric pressure, etc. Toxic, Corrosive	-162°C, atmospheric pressure Not toxic
Direct use	N/A. (no change in chemical properties)	No, at this point in time	Yes (e.g., co-firing with coal)	Yes (as an alternative to city gas)
Additional facilities to achieve high purity	Not required	Required (dehydrogenation)	Required (dehydrogenation)	Required (dehydrogenation)
Use of existing infrastructure	No to international transport (new infrastructure needed) Yes to domestic delivery	Yes (e.g., chemical tankers)	Yes (e.g., chemical tankers)	Yes (e.g., LNG tankers, city gas)
Technological challenges	Development of large-scale maritime transport technology (e.g., large liquefiers, carriers)	Further reduction of energy loss	Technological development for expansion of direct use and dehydrogenation facility	Supply of CO <sub>2</sub> and competitive green hydrogen at production site, which is essential

Source: Ministry of Economy, Trade and Industry of Japan: "The current situations surrounding hydrogen/ ammonia and future directions" (highlighted in a blue flame by MHI)

Figure 1 Superiority of ammonia as hydrogen carrier

## 2. The concept of ammonia cracking technology

With the spread of co-firing of ammonia with coal for power generation for fuel transition in chemical plants, demand for hydrogen from small and medium-sized consumers is likely to come first. Introducing a decentralized medium-scale ammonia cracking system installable in the demand area (with a processing capacity class of 0.25-2.5 t/day) makes it possible to meet a wide range of demand while minimizing the initial investment. Once hydrogen demand increases in the future, MHI will consider the launch of a large ammonia cracking system to handle large-scale demand from, for example, hydrogen power generation or hydrogen steelmaking. Figure 2 is a conceptual diagram of implementing Hydrogen Mitsubishi Ammonia Cracking System (hereinafter referred to as HyMACS®), ammonia-cracking and hydrogen-production technology developed by MHI.

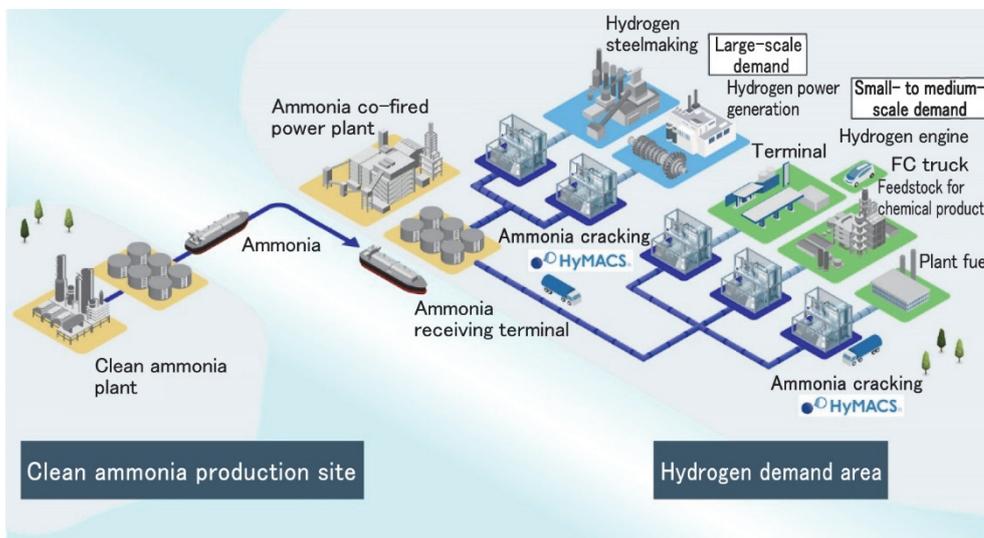


Figure 2 Conceptual diagram of implementing steam®

In HyMACS®, liquefied ammonia is pressurized/vaporized before being thermally decomposed in the presence of an ammonia cracking catalyst (endothermic reaction). This process is characterized by the following:

Firstly, steam/flue gas heating improves, thermal efficiency and reduces operational costs compared with fuel-fired furnace heating.

Secondly, the low-temperature, high-activity non-precious-metal catalyst enables catalytic cracking at heat-source temperatures at or below approximately 500°C, allowing for more compact reactors and reducing the nitriding risk in metallic materials (Figure 3 compares different types of processes).

Thirdly, the ammonia that remained uncracked after the feed gas was treated goes through

the ammonia recovery unit for removal and reuse. The hydrogen purification unit is capable of producing a high purity of hydrogen by separating nitrogen.

The combined adoption of steam/flue gas heating and a low-temperature active catalyst makes it possible for the equipment to be modularized into compact container-sized skids, thereby keeping the on-site construction work to a minimum and enabling quick installation.

	Steam/flue gas heating	Fuel-fired furnace heating (*2)	Autothermal reforming (*3)
Heat for reaction	Provided from outside	Self-produced	Self-produced
Reaction temperature	450–500°C	≈700°C	≈700°C
Operational cost	1.0	≈1.2 (*1)	≈1.2 (*1)
Technology Readiness Level	Medium	High	Low
Risk of nitriding	Low	High	Low
Catalyst's moisture durability	Measures taken	N/A	Measures required
Plot size	Small to Medium	Large	Large
Practical scale of equipment	0.25–2.5 t/day	>10 t/day	>25 t/day

In development

HyMACS

(\*1) Estimated by MHI  
 (\*2) The heat required is obtained by burning fuel in the vicinity of the reactor.  
 (\*3) The heat required is obtained by allowing some of the ammonia in the reactor to be burned as a fuel.

**Figure 3 Comparison of different types of processes**

### 3. Demonstration test facility and plan

#### 3.1 Laboratory test (bench-scale)

Prior to working on a pilot plant, the basic performance of the ammonia cracking catalyst was evaluated using the bench test equipment in MHI's Research & Innovation Center (Nagasaki District). Regarding the catalyst for use in the pilot plant, data on reduction/oxidation behavior, cracking reaction and heat transfer were obtained to establish a method to predict the behavior of ammonia cracking in the catalyst layer. The outcomes were applied to the design of the pilot plant.

#### 3.2 Summary of pilot plant facility and ammonia cracking/hydrogen purification test

A pilot plant, which is made of a cut-out reactor tube with the same length as the actual unit, was installed in the Research & Innovation Center (Nagasaki District). Based on the bench test verification results of underlying technologies, ammonia cracking, absorption and hydrogen purification are examined to assess the feasibility of the system as a whole.

The pilot plant is mainly comprised of the following: liquefied ammonia storage tank, ammonia pressure-boosting/vaporization equipment, ammonia cracking reactor (filled with low-temperature active catalysts), ammonia absorption/removal tower and recovery tower (ammonia recovery unit), hydrogen purification unit, utilities, and safety monitoring and emergency flue gas treatment equipment. The reactor uses steam as a heat source. Precautions against nitriding of reactor materials have been taken by means of temperature control, ammonia concentration control and selection of materials. With a view to scaling up for practical application, the pilot plant was configured in such a way that data for catalyst performance, system validity verification, hydrogen purification performance, operational safety, and catalytic oxidation/reduction can be collected. **Figure 4** shows an exterior view of the pilot plant.

In this pilot plant, steam was used as a source of heat to crack the ammonia and produce hydrogen. It was confirmed that the product hydrogen had a purity of 99.97%.



Figure 4 Exterior view of pilot plant

### 3.3 NEDO's grant and support

From now on, this development will be conducted as part of the "Development of Technologies for Building a Competitive Hydrogen Supply Chain" project of the New Energy and Industrial Technology Development Organization (hereinafter referred to as NEDO). Being responsible for Front-End Engineering Design (hereinafter referred to as FEED) and equipment design, MHI will take on the technological challenges for productization and determine the specifications of the demonstration plant by fiscal 2026. With regard to the catalyst, the basic data has been collected through in-house research. With NEDO's funding, MHI aims to overcome technological hurdles, assess the durability of the catalyst and further enhance the catalyst's activity at low temperatures.

### 3.4 About demonstration test plan

The testing is carried out in stages according to the roadmap shown in Figure 5. The function verification of the entire system is currently under way using the pilot plant, which was designed based on the catalyst characteristics obtained by the laboratory test. In the demonstration test to be conducted, catalyst durability, nitriding behavior, etc., will be evaluated. The construction of the demonstration plant and long-term durability testing are scheduled for fiscal 2028 or after. MHI's goal is to provide its first commercial unit in the first half of the 2030s.

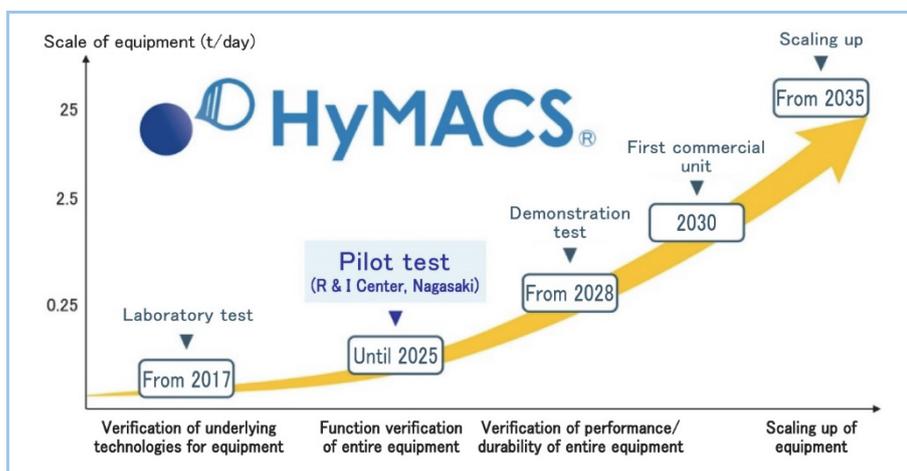


Figure 5 Technological development roadmap for hydrogen production by ammonia cracking

## 4. Conclusion

This report presented MHI's development policy and demonstration test plan for a decentralized medium-scale ammonia cracking system with the use of waste heat. By combining a non-precious metal-based catalyst that is highly active at low temperatures with steam/flue gas heating, it is expected to lower operational costs, achieve the compact design of the equipment and minimize the risk of nitriding. The catalytic reaction characteristics and the nitriding behavior of reactor materials are examined by the pilot test, before moving on through FEED to the next step of

long-term testing using a demonstration unit. The future challenges include evaluating the long-term durability of the catalyst (especially under the conditions in which ammonia contains water), optimizing the measures against nitriding of reactor materials, stabilizing the operation despite a fluctuating waste-heat source, and assessing the economic efficiency. By solving these issues, MHI believes that it can help build a flexible and competitive hydrogen supply infrastructure that is tailored for an area with hydrogen demand.

HyMACS® is a registered trademark of Mitsubishi Heavy Industries, Ltd. in Japan and other countries.

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