Ammonia Cracking Technology Development

Innovative Technology Series*

Mizuho Short Industry Focus Vol. 229
July, 2024

Tran Nguyen
Mizuho Bank Industry Research Department

* Series of reports highlighting areas of technology and innovation that can contribute to strengthening the competitiveness of Japanese industry and to solving social issues

Summary

- Ammonia cracking technology could become crucial in the future, as ammonia is recognized as one of the potential hydrogen carriers due to its superior properties, the possibility of deploying the existing value chain, lower transportation and investment costs over long distances compared to other hydrogen carriers such as LH2 and LOHC. Ammonia is considered as the most viable hydrogen transport carrier globally. In contrast, LH2 and LOHC are more popular in Japan
- The most popular ammonia cracking methodology, thermo-catalytic cracking, is predominantly owned by European and American companies. However, it faces many challenges, including high cracking costs, low efficiency, and unstable operation. Japanese hydrogen carrier suppliers, EPC contractors, and component manufacturers have been intensifying their R&D efforts since 2023, thanks to support from NEDO
- Based on the global demand for centralized ammonia cracking, Japanese companies can invest R&D efforts into the design and EPC of centralized systems, including components such as catalysts, to seize business opportunities and prevent the outflow of national wealth from the country. However, while Europe has advanced to the demonstration stage and South Korea has secured EPC contracts for commercial ammonia cracking projects, Japanese companies have been hesitant to make decisive investments in the technology due to the difficulty in forecasting domestic hydrogen demand
- Therefore, the government support is expected to create hydrogen demand such as in gas co-firing power generation and steel manufacturing by prioritizing the procurement of green products. Simultaneously, increasing the R&D support budget for ammonia cracking technology, innovative ammonia synthesis technology, and prioritizing support for the development of ammonia reception facilities with ammonia cracking facilities included should be considered

Source: Compiled by Mizuho Bank Industry Research Department

Table of Contents

Purpose of This Research

- Ammonia cracking technology could become crucial in the future, as ammonia is considered the most viable hydrogen transport carrier globally
- This report aims to promote ammonia cracking as a priority R&D technology, and facilitate its global expansion

Issues Awareness

Deployment of Ammonia Cracking	【Global】 • Ammonia demand as hydrogen carrier is expected to reach 127MT in 2050 (18% of the ammonia demand) • Centralized cracking is considered the most in Europe and Korea. Few projects are considered in Singapore and Thailand	【Japan】 • Centralized cracking is being given preliminary consideration in 4 reception terminals
R&D Trends in Ammonia Cracking Technology	【Europe, US】 • The thermo-catalytic methodology, which has the highest TRL of 8-9, is predominantly owned by major European companies. Recently, venture companies in Europe and the US have initiated R&D efforts to improve energy efficiency	【Japan】 • The development of plasma methodology, components including catalyst is currently underway
Challenges	【The World】 • Cracking cost is about 48% of mid stream cost • Significant energy input required for cracking • Temperature management in decomposition tubes for stable operation • Improving the components materials in all areas through which ammonia passes to prevent nitridation and lengthening equipment lifespan	

Research Points

Chapter 1: Potential of Ammonia Cracking
- Ammonia Properties and Outlook for Ammonia Demand
- Prospects for the Implementation of Ammonia Cracking around the World

Chapter 2: Ammonia Cracking Technology
- Introduction of Ammonia Cracking Technology
- Rooms for Improvement
- List of Technology Owners
- R&D in Japan

Chapter 3: Direction of R&D in Japan and Expected Policies to Support Companies
- The Direction of Technology Development in Japan
- Government Support in Promotion of Ammonia Cracking

Chapter 4: Export of Ammonia Supply Chain
- Export of ammonia supply chain to India and ASEAN

Source: Compiled by Mizuho Bank Industry Research Department

1. Potential of Ammonia Cracking

1.1 Ammonia Properties and Outlook for Ammonia Demand

Ammonia Properties and Ammonia Cracking in Midstream

- Considering favorable properties of ammonia such as density volume, liquefaction temperature, existing value chain and so on, ammonia may be a promising hydrogen storage and transport carrier
- Ammonia (NH_3), along with liquid hydrogen (LH2) and liquid organic hydrogen carriers (LOHC), is one of the hydrogen carriers. "Dehydrogenation (cracking)" is required to extract hydrogen from ammonia again. Energy loss in carrier conversion and dehydrogenation processes pose challenges

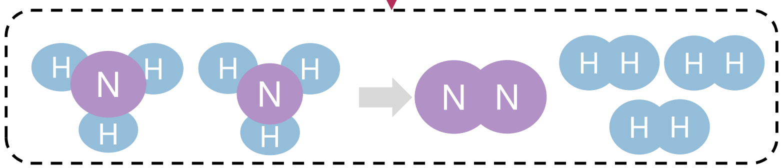
Ammonia Properties Comparison among Carriers

Properties	LH2	LOHC	NH_3
Density volume comparison with gaseous H_2 at 0.1MPa	1/800	1/500	1/1300
Liquefaction T at 0.1MPa (℃)	-253	N.A	-33.4
Energy loss due to properties changes	25-35% (Future: 18%)	35-40% (Future: 25%)	Synthesis 7-18% Reconversion: under 20%
Purification	Unnecessary	Necessary during dehydrogenation	
Lower heating value (kJ/ kg)	50,020	Direct use impossible	18,603
Flame speed (cm/s)	291	N.A	37
Existing infrastructure deployment	Possible for domestic only	Possible	Possible
Other challenges	High equipment cost for cryogenic temperature, boil-off, unready large-scale maritime transportation	The greatest energy loss during changes in properties among carriers	Direct combustion yields Nox, highly toxic to humans and aquatic life
Others	N.A	• Suitable for long distance H_2 transport • Suitable for long term H_2 storage	

Source: Compiled by Mizuho Bank Industry Research Department based on various sources

Ammonia Cracking in Midstream

Hydrogen Carriers	①Conversion	②Transport	③Reconversion
LH2	Liquefaction	Shipping	Regasification
LOHC	Hydrogenation	Shipping	Cracking
NH_3	Synthesis	Shipping	Cracking



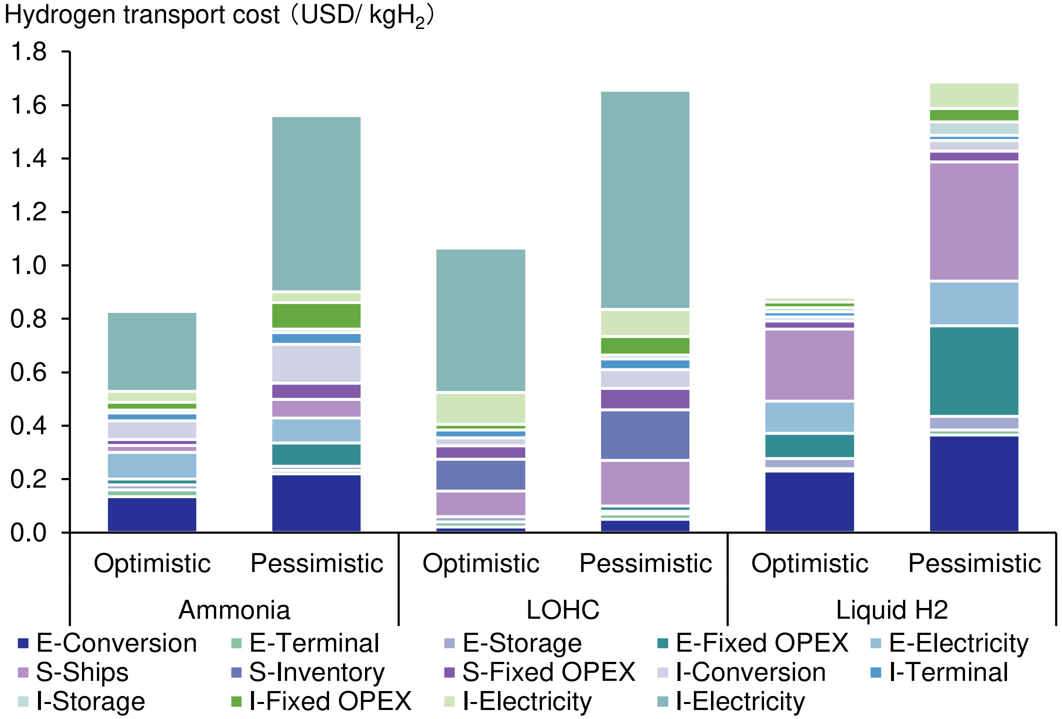
1. Thermocatalytic
2. Reforming
3. Plasma
4. Electrolysis
5. Photocatalytic

Source: Compiled by Mizuho Bank Industry Research Department

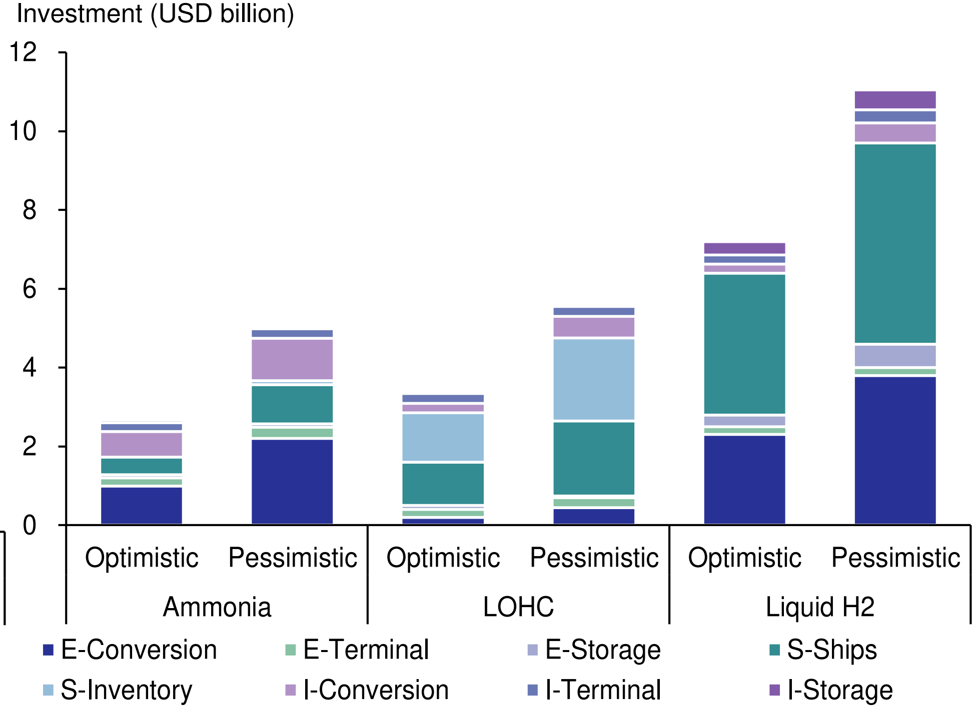
Comparison of Midstream Cost and Capital Cost among Hydrogen Carriers

- Ammonia is a hydrogen carrier that is suitable for long-distance transport (ex: 10,000 km), which is significant for Japan – a potential import country
  - For example, the distance from Middle East, the cheapest ammonia producer, to Japan is more than 12,000 km
- Ammonia also has the advantage of requiring the lowest total amount of capital for a fixed hydrogen capacity, about 20% lower than the total investment needed for LOHC and 50% lower than liquid hydrogen. Liquid hydrogen has more expensive conversion, storage and shipping, while LOHC requires double the shipping capacity

Midstream Cost Breakdown by Hydrogen Carrier



Capital Cost Breakdown by Hydrogen Carrier



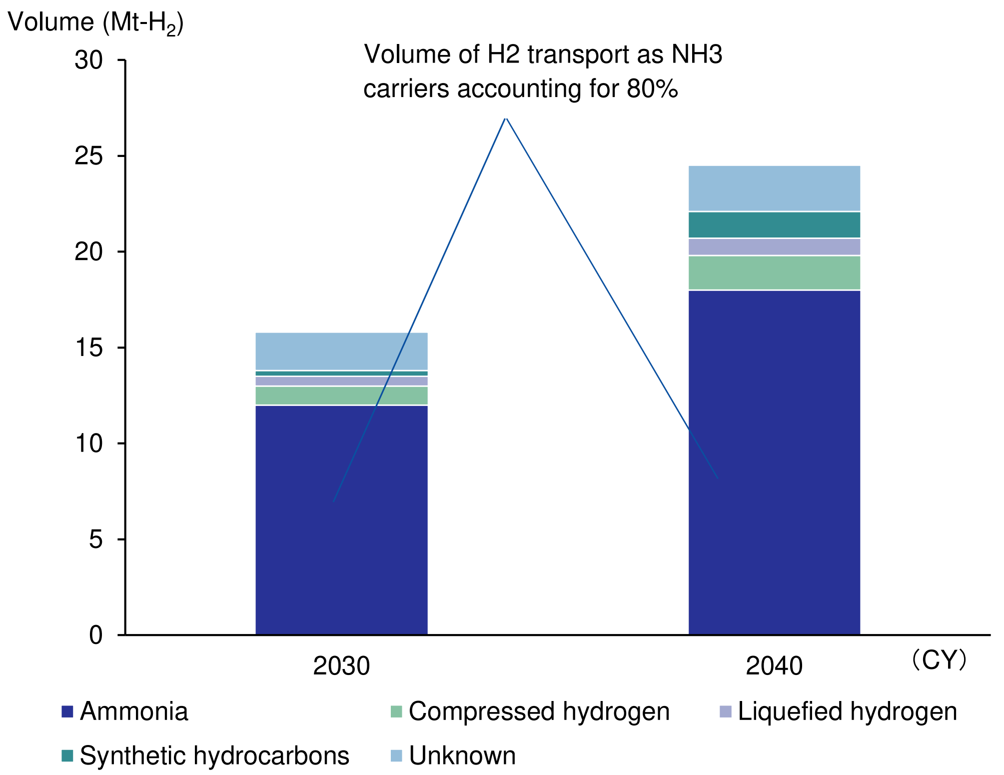
Notes: Costs of both graphs are for a 1 MtH2/yr export flow and a distance between ports of 10,000 km. Cost components are divided by part of the value chain: E = exporting country; S = ships; I = importing country.

Source: Both figures are compiled by Mizuho Bank Industry Research Department based on IRENA, GLOBAL HYDROGEN TRADE TO MEET THE 1.5° C CLIMATE GOAL: PART II – TECHNOLOGY REVIEW OF HYDROGEN CARRIERS

Global Ammonia Demand as Hydrogen Carrier Is Expected to Increase

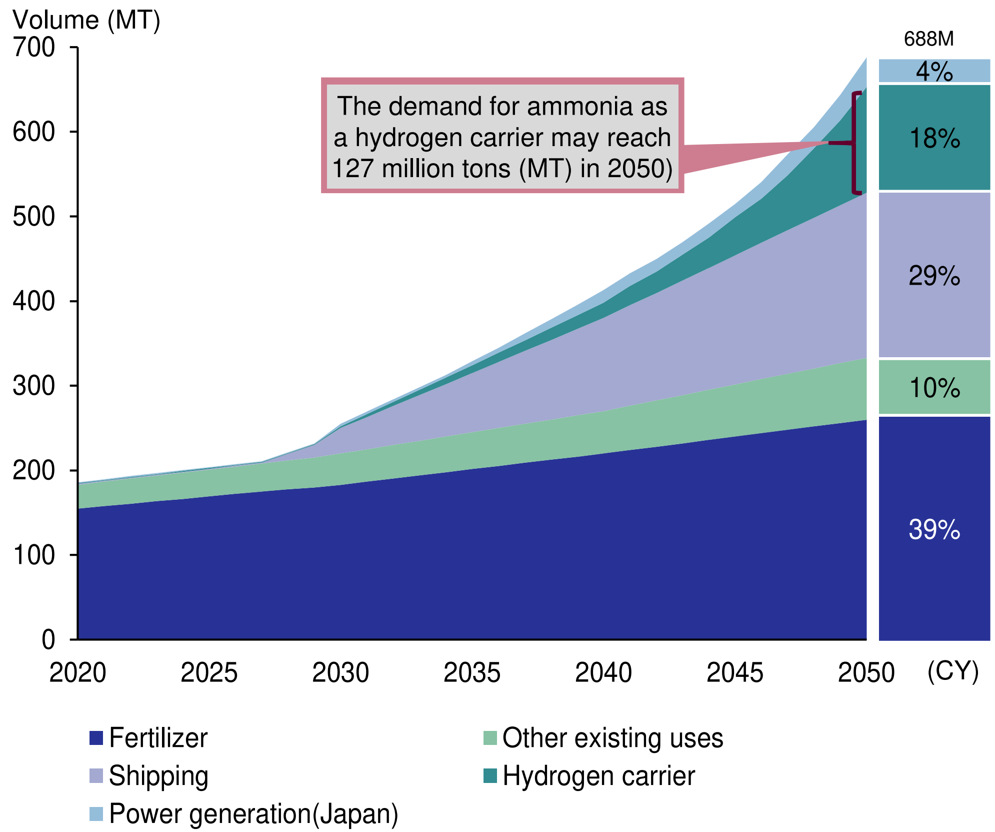
- Even until 2040, ammonia transport as hydrogen carrier will account for about 80% of hydrogen announced export-oriented projects due to its superior properties, ability to deploy the technology on existing value chain, lower long-distance transportation cost compared to other hydrogen carriers. Ammonia cracking allows users to leverage ammonia's transport efficiencies and hydrogen's fuel properties
- Up to 2050, ammonia demand as a hydrogen carrier is forecast to be 127 MT, contributing about 18% to total ammonia demand of 688 MT, and 36% to new demand (shipping, H2 carrier, power generation) of 354 MT

Transport Carriers Based on H2 Export Announced Projects



Source: Compiled by Mizuho Bank Industry Research Department based on IEA, Global Hydrogen Review 2023

Breakdown of NH3 Demand in 2050 (1.5℃ scenario)



Source: Compiled by Mizuho Bank Industry Research Department based on IRENA, Innovation Outlook Renewable Ammonia

1. Potential of Ammonia Cracking

1.2 Prospects for the Implementation of Ammonia Cracking around the World

Types of Ammonia Cracking

- Ammonia cracking can be divided into centralized and decentralized. In the centralized scenario, ammonia is transported to a large cracking plant situated close to a terminal, and then hydrogen is distributed to the point of use. In the decentralized scenario, ammonia is transported to the point of use and cracked onsite
- This report primarily focuses on centralized cracking because the market size is larger and the contribution to CO2 reduction is more significant than decentralized cracking

Comparison of Ammonia Cracking Types

	Centralized Ammonia Cracking	De-centralized Ammonia Cracking
Application	• Large scale hydrogen generation for industrial complex, power plant, H2 station, etc	• Onsite small scale hydrogen generation for fuel cell, power generation, H2 station, hard-to-abate factories etc including remote areas
Catalyst	• High temperature catalyst (Ex: Ni-based [Note 1])	• Low temperature catalyst (Ex: Ru-based [Note 2])
Energy Input	• Ammonia, hydrogen, separation waste gas from cracking process	• Electrically heated crackers are more likely to be a feasible solution for decentralized cracking systems, where efficiency and safety aspects of design would be ensured than using a fired heater
Purification	• Well-established purification technology – pressure swing absorption (PSA) can deliver high recovery rates • Cryogenic distillation and membranes can also be used	• Palladium membrane separation can be used to deliver purity required for fuel cells but hasn't been technically proven to operate on commercial scale
Advantages	• Cost of catalyst (Ni-based) is low • Reactors can be run continuously at high temperature and pressures, so efficiency is achieved • Economies of scale	• Low CAPEX • Occupies minimal land area • Ammonia is convenient for on-site transportation and storage
Disadvantages	• High CAPEX • A certain land area is required • Heat management between the decomposition tubes to ensure stable operation is difficult	• Cost of catalyst (Ru-based) is high • Users need ammonia handling knowhow and experience

Note 1: Nickel
Note 2: Ruthenium
Source: Compiled by Mizuho Bank Industry Research Department based on various sources

Centralized Ammonia Cracking Projects Under Consideration in the World

- The biggest planned cracking project in the world is at The Port of Rotterdam (1MTH2PA). Cracking hydrogen is expected to mainly use for industrial complexes in North-West Europe
- JERA has been considering 2 cracking projects in Germany and Thailand
- Cracking technology providers, and ammonia suppliers from Europe have been expanding their businesses in Korea and Singapore. Cracking hydrogen is expected to mainly be used for power generation in Korea, industry and mobility in Singapore

The Biggest Project in Europe (2022)

Netherlands (Ex: Port of Rotterdam)	Ammonia cracking technology provider: Fluor	Ammonia supplier: Air Liquide / ExxonMobil / Sasol Shell / Uniper / BP / OCI Global
	Tank, etc, middle stream relevant services provider: Vopak / HES International / Gasunie / Koole Terminals / VTTI Global Energy Storage	Energy company, the others: RWE / Shell / Aramco Essent / Port of Rotterdam

- An initiative of 18 companies, led by the Port of Rotterdam Authority, has kicked off a study into the possible establishment of a large-scale ammonia cracker, which will enable the imports of 1 MTH2PA for industries and mobility

European Companies Have Been Expanding Business in Asia (2024)

Korea	Ammonia cracking technology provider: TOPSOE	Hydrogen manufacturer: APPROTIUM

- Engineering agreement signed on Mar, 2024
- Cracking hydrogen (75,000 TH2PA) is expected to use for power generation
- Topsoe will provide H2RETAKE designed for the high-efficiency conversion (96%)

Singapore	Ammonia supplier: Air Liquide	Tank, etc, middle stream relevant services provider: Vopak

- Both companies intend to develop and operate NH3 import infrastructure, cracking facility and hydrogen distribution for industry and mobility basing on Vopak's refrigerated NH3 tank (10,000 m³) at Banyan terminal complex based on Jurong
- Besides hydrogen, ammonia is used for power generation and marine fuel

Japanese Company Is Considering a Pilot Project in Europe (2023)

Germany	Energy company: JERA / EnBW	Gas company: VNG

- The project partners have jointly conducted a feasibility study to evaluate the construction of an ammonia cracker demonstration plant

Japanese Company Is Considering Supply Chain in Asia (2023)

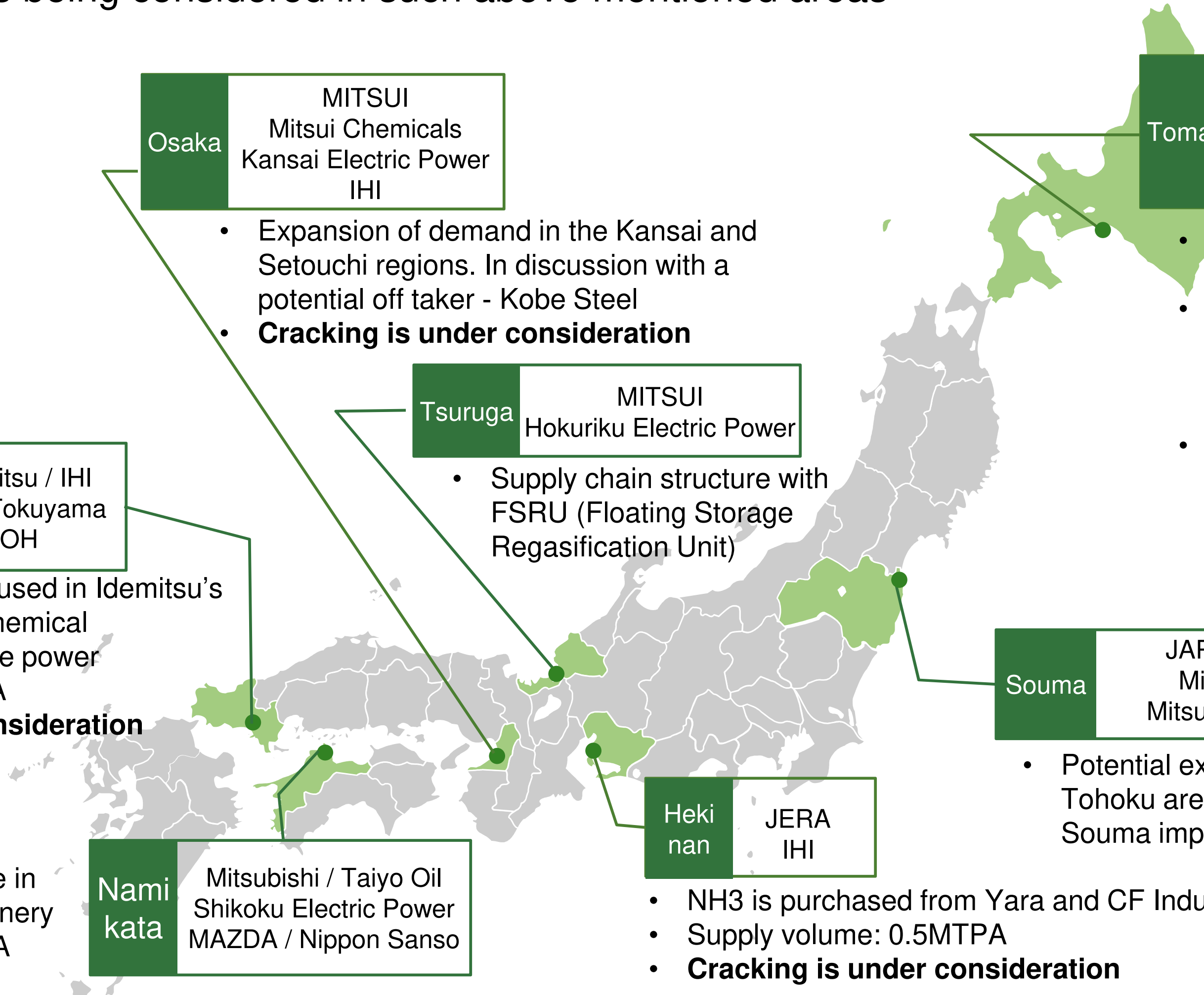
Thailand	Energy company: JERA	Energy company: PTT Group

- JERA and PTT jointly considered possibilities of hydrogen and ammonia supply chain including ammonia cracking. The feasibility of ammonia cracking technology as a mean of supplying hydrogen in Thailand will be evaluated

Source: All figures are compiled by Mizuho Bank Industry Research Department based on companies' public materials

Japan is Preparing for Ammonia Import Infrastructure

- There are 7 potential ammonia reception terminals in Japan. Ammonia cracking is being given preliminary consideration in Osaka, Hekinan, Shunan, Tomakomai
- In Japan, ammonia is primarily used for co-firing with coal. In addition, hydrogen obtained from centralized ammonia cracking being considered for supply to other industries afterward. The value chain model, which includes both co-firing and cracking, is being considered in such above mentioned areas



Osaka — MITSUI / Mitsui Chemicals / Kansai Electric Power / IHI
- Expansion of demand in the Kansai and Setouchi regions. In discussion with a potential off taker - Kobe Steel
- **Cracking is under consideration**

Tomakomai — MITSUI / IHI / Marubeni / Hokkaido Electric Power / Tomakomai Futo / Hokkaido Mitsui Chemicals
- Joint study for the establishment of an ammonia supply chain
- In discussion with potential off-takers such as Kushiro Power Station, Nippon Beet Sugar Manufacturing, Oenon Holdings
- **Cracking is under consideration**

Tsuruga — MITSUI / Hokuriku Electric Power
- Supply chain structure with FSRU (Floating Storage Regasification Unit)

Shunan — Marubeni / Idemitsu / IHI / Tokyo Century / Tokuyama / Zeon / TOSOH
- NH3 is expected to be used in Idemitsu's naphtha cracker and chemical manufacturers' in-house power
- Supply volume: 1MTPA
- **Cracking is under consideration**

Souma — JAPEX / MITSUI / IHI / Mitsui O.S.K. Lines / Mitsubishi Gas Chemical
- Potential expansion into Tohoku area based on Souma import terminal

Hekinan — JERA / IHI
- NH3 is purchased from Yara and CF Industries
- Supply volume: 0.5MTPA
- **Cracking is under consideration**

Namikata — Mitsubishi / Taiyo Oil / Shikoku Electric Power / MAZDA / Nippon Sanso
- NH3 is expected to use in power plant and oil refinery
- Supply volume: 1MTPA

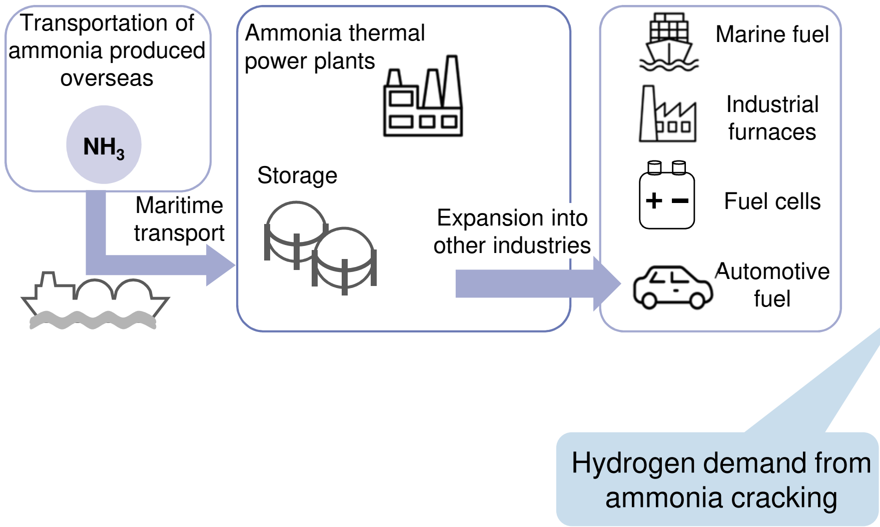
Note: Company logos indicate the locations where NH3 is received based on the companies' releases
Source: Compiled by Mizuho Bank Industry Research Department based on companies' public materials

MIZUHO

Centralized Ammonia Cracking Projects Under Consideration in Chubu Area

- Ammonia will be used in the thermal power plants in Hekinan, and hydrogen derived from ammonia will be supplied to other industries such as automobile manufacturing, thermal power plants, and hard-to-abate sectors
- Centralized ammonia cracking facilities are being considered in Chita, Mikawa Port, and Yokkaichi Port (starting from 2030). The estimated hydrogen demand from ammonia is about 200,000 tons per year from 2027 to 2030, and more than 240,000 tons per year from 2030 to 2040

Ammonia Supply Chain in Chubu Area



Estimated Demand for Ammonia and Hydrogen in Chubu Area

CN Fuel	Production Method	Domestic Supply Areas	Major Demand	Volume (ton/ year)	
				2027-2030	2030-2040
Hydrogen	From plastic waste	Chita	Automobile manufacturing	5,000	5,000
Hydrogen	From ammonia	Chita, Mikawa Port, Yokkaichi Port (since 2030)	Automobile manufacturing, thermal power plant, refinery, steel mill, chemical factories, hydrogen station	200,000	Min 240,000
Ammonia	Overseas Production	Hekinan	Thermal power plant, automobile manufacturing	1,000,000	2,500,000

Source: Both figures are compiled by Mizuho Bank Industry Research Department based on public materials

2. Introduction of Ammonia Cracking Technology

Ammonia Cracking Methodologies – Thermo-catalytic

- The most popular ammonia cracking methodology is thermo-catalytic
  - TRL of Ni-based catalyst methodology can reach its highest at 8-9
- The catalysts, burner and plant engineering play a very important role in thermo-catalytic methodology

Ammonia Cracking Methodologies – Thermo-catalytic

Methodologies		TRL Note 1	Features	Pros	Cons	T [℃]	P[bar] Note 2	H2 Yield
Thermo-catalytic	Ni/Co/Fe-based catalysts	8-9	• The decomposition occurs at moderate to high temperatures with suitable catalysts • Less expensive catalysts possibly active under milder temperature are necessary	• Cheaper than Ru-based catalysts • Good heat resistance and stability	• Higher reaction temperature than Ru-based catalyst	600-900	atmospheric	High
	Ru-based (precious metal) catalysts	3-4		• Most studied active species • Lowest activation energy	• Very expensive material • High global warming potential, scarcity of the noble metal	400-500	atmospheric	High
	Amide - imide catalyst	3-4		• Low cracking temperature • Conversion comparable to Ru-based catalysts	• Difficult to keep the catalysts in solid phase at the reaction → a combination of 2 transition metals can be considered • Unclear reaction mechanism	<500	atmospheric	High

Note 1, Note 2: The values are on a small scale
Source: Compiled by Mizuho Bank Industry Research Department based on I&EC, Ammonia as a Carbon-Free Energy Carrier: NH3 Cracking to H2

Ammonia Cracking Methodologies – The Others

Methodologies		TRL Note 1	Features	Pros	Cons	T [℃]	P[bar] Note 2	H2 Yield
Reforming		3-4	• Through the combustion of ammonia and oxygen, ammonia is decomposed, yielding hydrogen, water, nitrogen, and nitrogen oxides	• The energy input required is reduced due to the endothermic reaction	• DeNox system needed for Nox abatement	>500	atmospheric	High
Plasma	Plasma (Thermal)	3-4	• The gas is heated to generate a plasma state, which facilitates the ammonia decomposition	• Owing to the higher temperatures than conventional cracking, the conversion rate is higher	• Energy input is required for plasma generation	1,500～	atmospheric/ subatmospheric	High
	Plasma (Non-thermal)	3-4	• Gas is turned into plasma at low temperatures within an electromagnetic field generated by electricity, and ammonia is decomposed in this environment	• Cracking can be achieved at room temperature, it requires a minimal energy input	• The reaction efficiency decreases due to low gas flow rate	Ambient or slightly higher	atmospheric/ subatmospheric	Low
	Catalyst combining plasma	3-4	• After activating ammonia molecules with plasma, the ammonia decomposition is facilitated by a catalyst	• High energy efficiency	• The optimal selection of catalysts and the optimization of plasma generation have not yet been established	Ambient or slightly higher	atmospheric/ subatmospheric	Low
Electrolysis		3-4	• Electricity is applied to an ammonia solution, subsequently generate hydrogen at the electrodes	• No CO2 emitted • Low reaction temperature	• High cost of electrocatalysts due to the noble metal • Electrode's corrosion for aqueous ammonia oxidation	Ambient	atmospheric	Low
Photocatalysis		3-4	• Ammonia is decomposed at room temperature using light (photon energy) and a photocatalyst	• Energy required is minimal • No CO2 emitted • Low reaction temperature	• Most of the available photocatalyst suffer from poor activity, low stability, low surface area, complicated synthesis approach • Nox generated that lower H2 yield	Ambient	atmospheric	Low

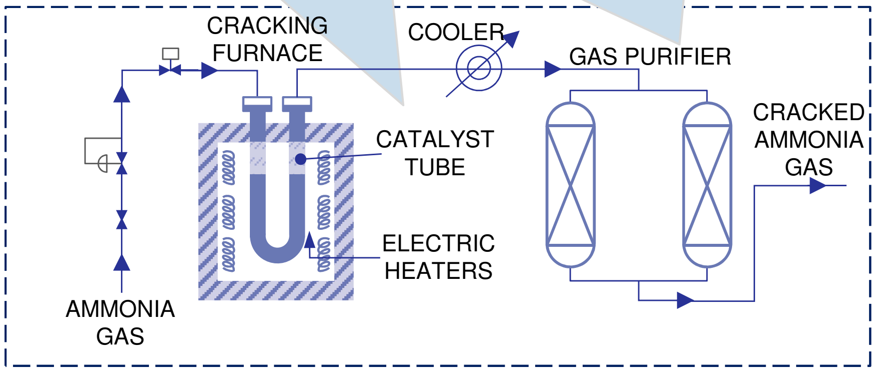
Note 1, Note 2: The values are on a small scale
Source: Compiled by Mizuho Bank Industry Research Department based on I&EC, Ammonia as a Carbon-Free Energy Carrier: NH3 Cracking to H2

Rooms for Improvement for the Thermo-catalytic Methodology (Centralized Cracking)

- Developing catalysts for lower cracking temperature, improving reactor design for stable operation and reducing energy loss are critical challenges that need to be overcome for the commercialization of large-scale cracking
- Cracking cost accounts for the highest proportion of ammonia total midstream cost, approximately 48% (for a transportation distance of 12,000 km). Of this, CAPEX and OPEX constitute 25%, and energy costs make up 23%

Rooms for Improvement for the Thermo-catalytic Methodology

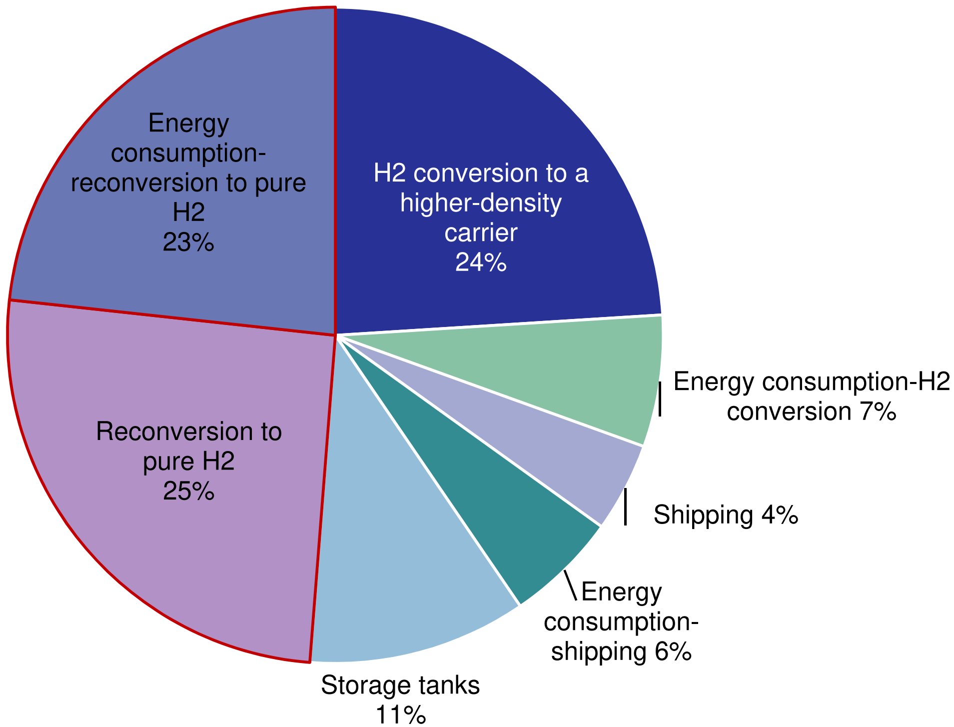
1. Enhancing the catalyst to improve the NH3 conversion rate and lower the cracking temperature
2. Developing purification equipment to increase hydrogen purity



3. Improving reactor design to ensure stable operation, reduce energy loss. Stable operation only can be achieved if a consistent tube is maintained
4. Improving the materials of components in all areas through which ammonia passes to prevent nitridation and lengthen the lifespan of the equipment

Source: Compiled by Mizuho Bank Industry Research Department based on various sources

Proportion of Cracking Cost in Ammonia Middle-stream Cost (12,000 km)



Note 1: The cost per stage includes all capital and operational expenditures. The discount rate is 5%

Note 2: It is assumed that import and export terminals handle 20 shipments per year on average

Source: Compiled by Mizuho Bank Industry Research Department based on IEA, Energy Technology Perspectives 2023

Owners of Centralized Ammonia Cracking Technology (Thermo-catalytic）

- Almost all leading companies in centralized cracking technology are from Europe

List of Technology Owners, Partners and Sponsors（Thermo-catalytic）

	Technology Owners	Partners and Sponsors
Catalyst	Nippon Shokubai (JP); Clariant (DE) – Ni-based, Ru-based; BASF (DE） – Ni-based; Heraeus (DE) – Ru-based; Aramco (SA)	
Catalyst and Cracking Plant	Topsoe (DK) – Co-Fe, Fe, Ni, Ru-based; Johnson Matthey (UK) – Ni-based, Platinum Group Metal-based	
Cracking Plant	JGC Holdings; Mitsubishi Heavy Industries; Fluor (US); Thyssen Krupp (DE); KBR (US)	Toyo Engineering (JP) (EPC Partner of KBR (US))

Source: Compiled by the Mizuho Bank Industry Research Department based on various sources

R&D Projects on Centralized Ammonia Cracking in Japan

- R&D on catalyst, decomposition tube and purification equipment has started in 2023 thanks to NEDO's Development of Technologies for Building a Competitive H2 Supply Chain
- Since Apr 2024, Mitsubishi Heavy Industries (MHI) and NGK INSULATORS (NGK) have jointly developed a hydrogen purification system using membrane separation

Catalyst R&D Projects

Jun, 2023

JERA — Nippon Shokubai — CHIYODA

- JERA conducts bench tests to verify the performance of catalysts, evaluates catalysts and processes from the perspective of power generator, and identifies issues for industrial scale implementation
- Nippon Shokubai considers the development of catalysts by establishing a basic manufacturing method
- Chiyoda to design bench test equipment to verify catalyst performance as part of their efforts towards developing commercial equipment for large-scale ammonia cracking. This process aims to clarify challenges related to scaling up the equipment

Aug, 2023

Mitsubishi Heavy Industries — Nippon Shokubai

- The two companies have signed a joint development agreement for an ammonia decomposition system, with an eye towards the implementation of a hydrogen/ammonia supply chain
- Mitsubishi Heavy Industries contributes with its expertise in handling ammonia and hydrogen. Nippon Shokubai contributes with its catalysis technology

Other Components and Whole System (Design & EPC) R&D Projects

Jun, 2023

JGC — Kubota — TAIYO NIPPON SANSO

- The three companies are considering production of 110,000 tons hydrogen per year through ammonia cracking
- JGC Holdings is responsible for the overall supervision of the entire process, design and development of the cracking furnace, cost estimation and the demonstration plan
- Kubota is engaged in R&D of ammonia decomposition tubes
- Taiyo Nippon Sanso is responsible for the R&D of purification equipment
- The consideration of demonstration sites and support for the planning of demonstration are carried out by Idemitsu Kosan, a research vendor for JGC Holdings

Apr, 2024

Mitsubishi Heavy Industries — NGK INSULATORS

- MHI will contribute its expertise in delivering ammonia plants and other chemical plants, and its technologies for handling ammonia and hydrogen
- NGK will contribute its knowledge of subnano ceramic membrane technology and unique film deposition technology, which are known for their exceptional separation accuracy and durability

Source: Both figures are compiled by Mizuho Bank Industry Research Department based on companies' public materials

【For Reference】R&D Projects on Decentralized Ammonia Reformers in Japan

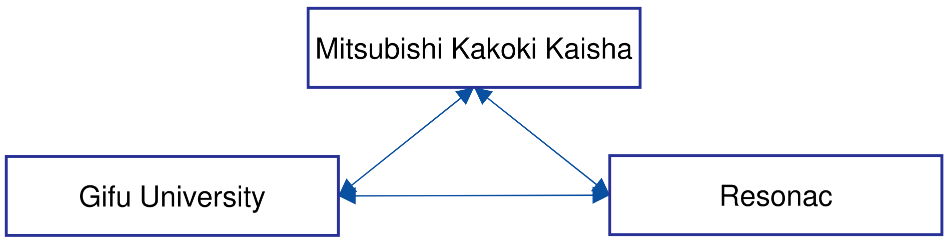
- Plasma Membrane Reactor using plasma methodology has been researched by Sawafuji Denki and Gifu University
- Gifu University, Mitsubishi Kakoki, and Resonac are collaborating on the R&D of an NH3 reformer for burners and fuel cells, as part of R&D theme "Ammonia Hydrogen Use Distributed Energy System" under the third phase of the SIP (Strategic Innovation Promotion Program)
- Toyo Engineering, Nippon Seisen, Chubu Electric Power, and Chubu Electric Power Miraiz have signed an MOU on joint developing and commercializing a compact ammonia reformer

Plasma Membrane Reformer (2019)

- Through joint research by Sawafuji Denki and Gifu University, plasma membrane reactor (PMR) using plasma has achieved high-purity hydrogen at a rate of 300 liters per hour as of May, 2019
- Obtained International patents for PMR in America, Germany and China

Ammonia Reformer for Burner and Fuel Cell (2023)

- Catalyst loadings and cracking temperature
- Design, manufacture and operation control of reformer
- Design, manufacture and demonstration testing of the reformers for burner and fuel cell



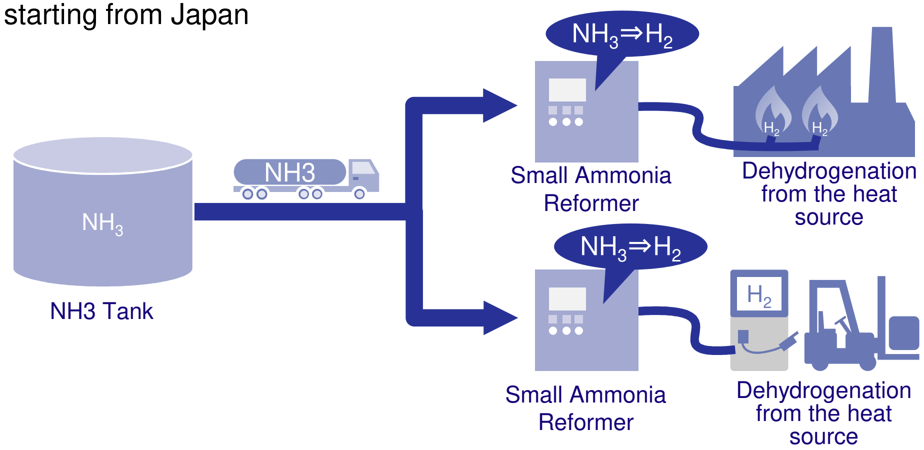
Gifu University:
- Development of a self-heating reformer
- Development of hydrogen separation equipment and ammonia removal equipment

Resonac:
- Catalyst development
- Catalyst mass production

Source: Both figures are compiled by Mizuho Bank Industry Research Department based on companies' public materials

Decentralized Ammonia Reformer (2024)

- Toyo Engineering and Nippon Seisen have been working on the development of a compact device for producing hydrogen from ammonia onsite so far
- As per the MOU, Chubu Electric Power and Chubu Electric Power Miraiz will conduct market research and economic evaluations for this device, as well as examine the technical requirements necessary for its practical application. Based on the feedbacks, Toyo Engineering and Nippon Seisen will advance the development of the equipment
- The four companies aim to achieve the commercialization of this device, starting from Japan



Source: Compiled by Mizuho Bank Industry Research Department based on companies' public materials

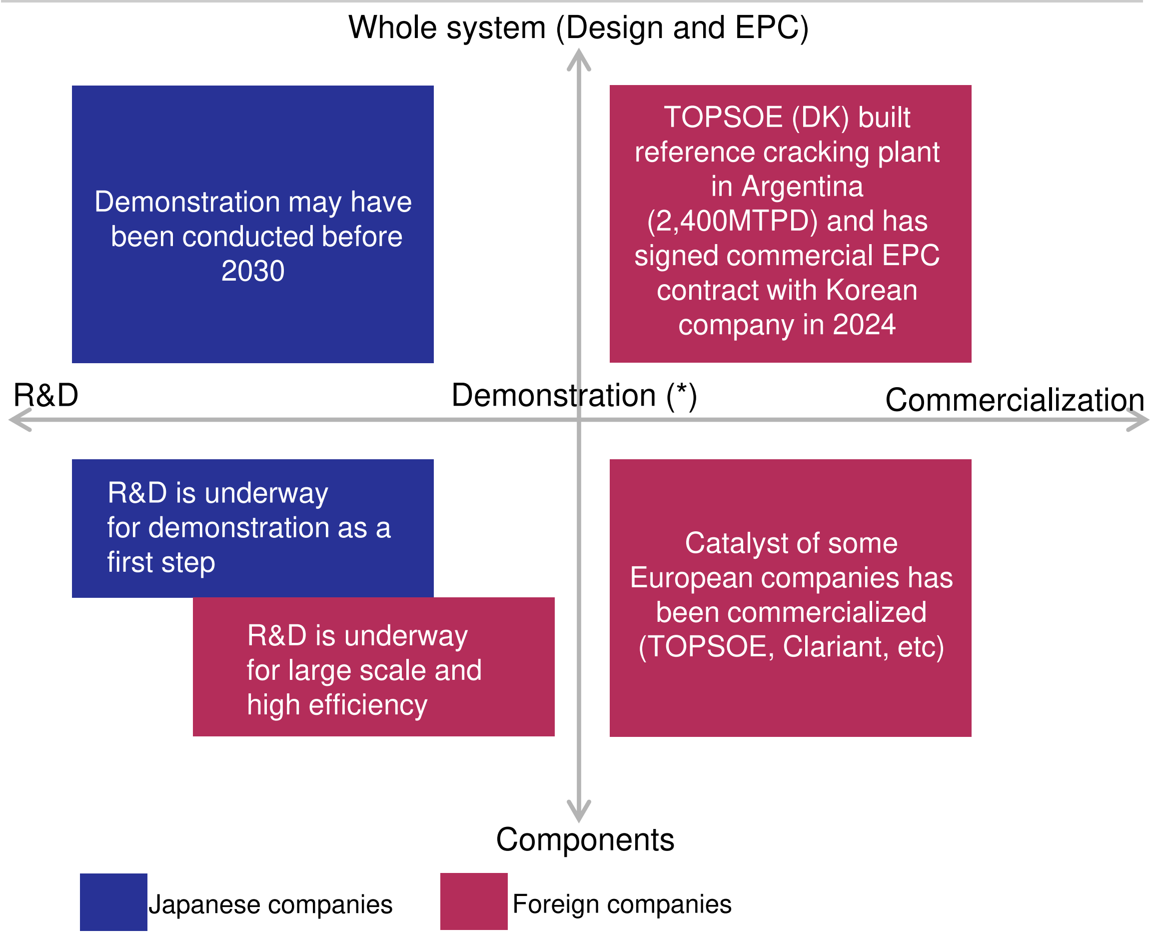
MIZUHO

3. Direction of R&D in Japan and Expected Policies to Support Companies

【Our Bank's Understandings】The Direction of Technology Development in Japan

- The demonstration and commercialization of centralized ammonia cracking technology in Japan is behind foreign companies, especially Europe
- In centralized cracking, Japanese companies are developing both components such as catalysts, separation membranes, heat-resistant tubes and the whole system (design and EPC)

Current Technology Development in the World



Note: "Demonstration" belongs to the horizontal axis and is not relevant to the vertical axis.
Source: Compiled by Mizuho Bank Industry Research Department

The Direction of Technology Development in Japan

Components

- Japanese companies are developing catalysts to reduce energy consumption and separation membranes to increase the purity of hydrogen, and heat-resistant tubes

Component	R&D Co	Strength
Catalyst	• Nippon Shokubai	• Background of catalyst technology
Separation membrane	• MHI • NGK	• Membrane technology in chemicals, etc
Tube	• Kubota	• High quality cracking tubes for refineries with 3 factories in Japan, Canada and Saudi Arabia

Whole System

- In Japan, centralized cracking might initially begin at reception terminals due to potentially high hydrogen for demand in industrial complexes. EPC companies are working to develop technologies and aim to conduct demonstrations before 2030

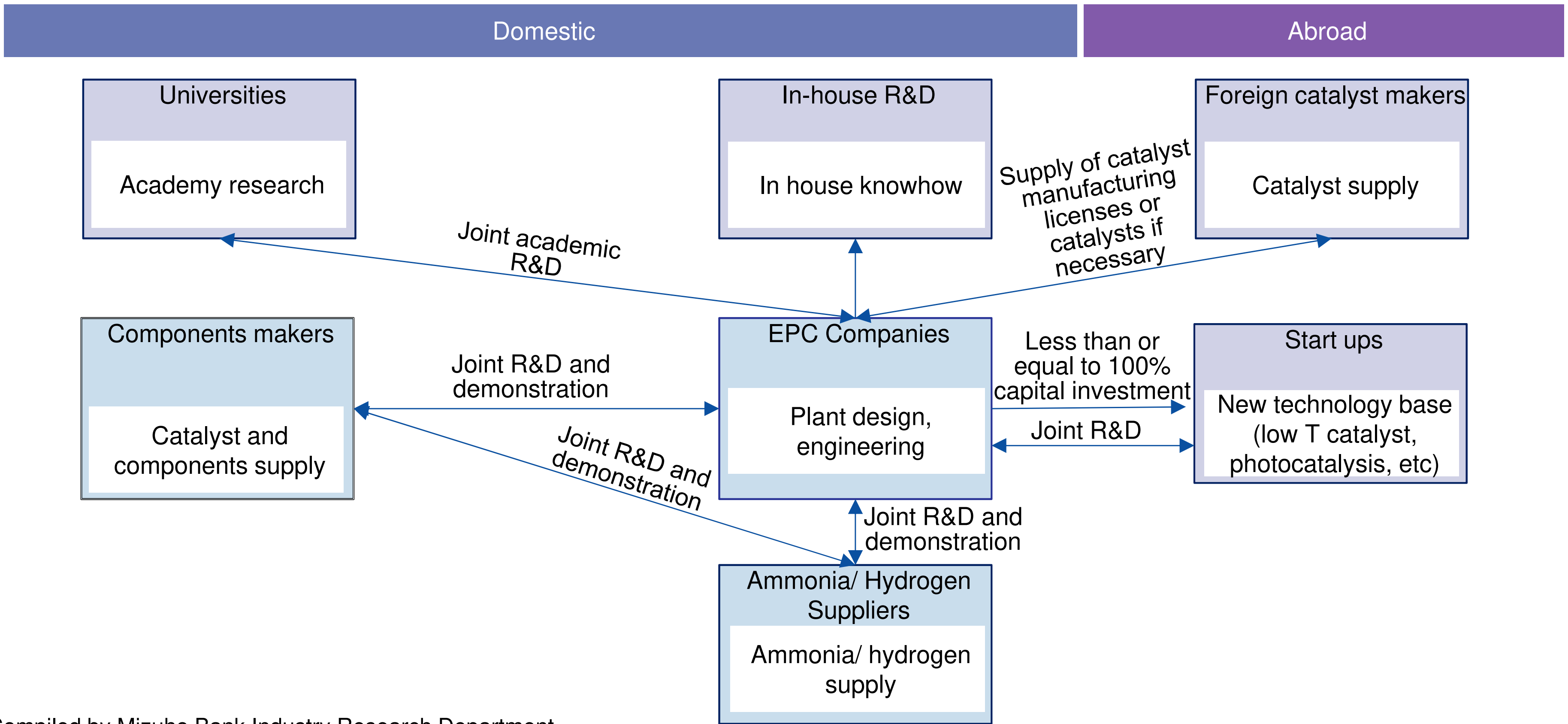
R&D Company	Strength
• JGC HOLDINGS CORPORATION • Mitsubishi Heavy Industries	• Licensed EPC provider for ammonia synthesis plant

Note: MHI: Mitsubishi Heavy Industries, NGK: NGK INSULATORS
Source: Compiled by Mizuho Bank Industry Research Department

【Our Bank's Assumption】Structure of R&D Promotion for Centralized Cracking

- Ammonia/ hydrogen suppliers which may become ammonia cracking plant operator should be involved in ammonia cracking technology development to manage the operation and ensure stable hydrogen supply once it's commercialized
- For EPC companies, in addition to cooperating with domestic component makers and ammonia/ hydrogen suppliers, investing in foreign startups with innovative technologies and engaging in joint academic R&D with universities are also crucial for successful R&D efforts. Furthermore, cooperation with foreign catalyst makers is necessary in case the catalyst can't be purchased from domestic catalyst makers

Solutions for R&D Promotion



Source: Compiled by Mizuho Bank Industry Research Department

【Our Bank's Assumption】Government Support in Ammonia Cracking Technology R&D

- R&D on ammonia cracking in Japan has been advancing smoothly, thanks to a solid technological foundation, government budget support, and effective collaboration among relevant stakeholders. However, challenges such as the difficulty of forecasting domestic demand and the scarcity of land area pose barriers to commercialization
- Government support, including the creation of demand, an increase in R&D budgets, and securing land, is expected to promote the use of ammonia as a hydrogen carrier

Challenges for Companies Considering Ammonia Cracking Business

Interview Results
- EPC Companies
- Component makers
- Ammonia and Hydrogen Suppliers

- Although we would like to proceed with the development of ammonia cracking technology, it is difficult to forecast the demand for hydrogen in Japan at this time, as hydrogen is expensive and consumers have a lower priority for fuel switching than coal-fired power

- While Europe and South Korea have entered the demonstration stage or EPC contract for commercial cracking project, Japanese companies still can not make the decision on how much they should invest in ammonia cracking technology

- There are cases where securing land area is difficult

Source: Compiled by Mizuho Bank Industry Research Department

← Government Support

Expected Government Support

Demand Creation
- Besides ammonia demand for co-firing with coal, the creation of hydrogen demand for gas co-firing in power generation and for transportation, steel manufacturing should also be considered (→ contributing not only to ammonia cracking but also to promoting the spread of liquefied hydrogen and LOHC)
- Prioritizing government procurement of green products which use hydrogen

Support for Technology R&D and Cost Reduction
- Promoting cost reductions throughout the ammonia supply chain by increasing R&D support budget for ammonia cracking technology and the commercialization of innovative ammonia synthesis technology
- Prioritizing support for ammonia reception facilities development where ammonia cracking is considered to be established

Others
- Central and local governments can collaborate to expand the scale of the receiving terminals or to gain the approval of local communities for land acquisition

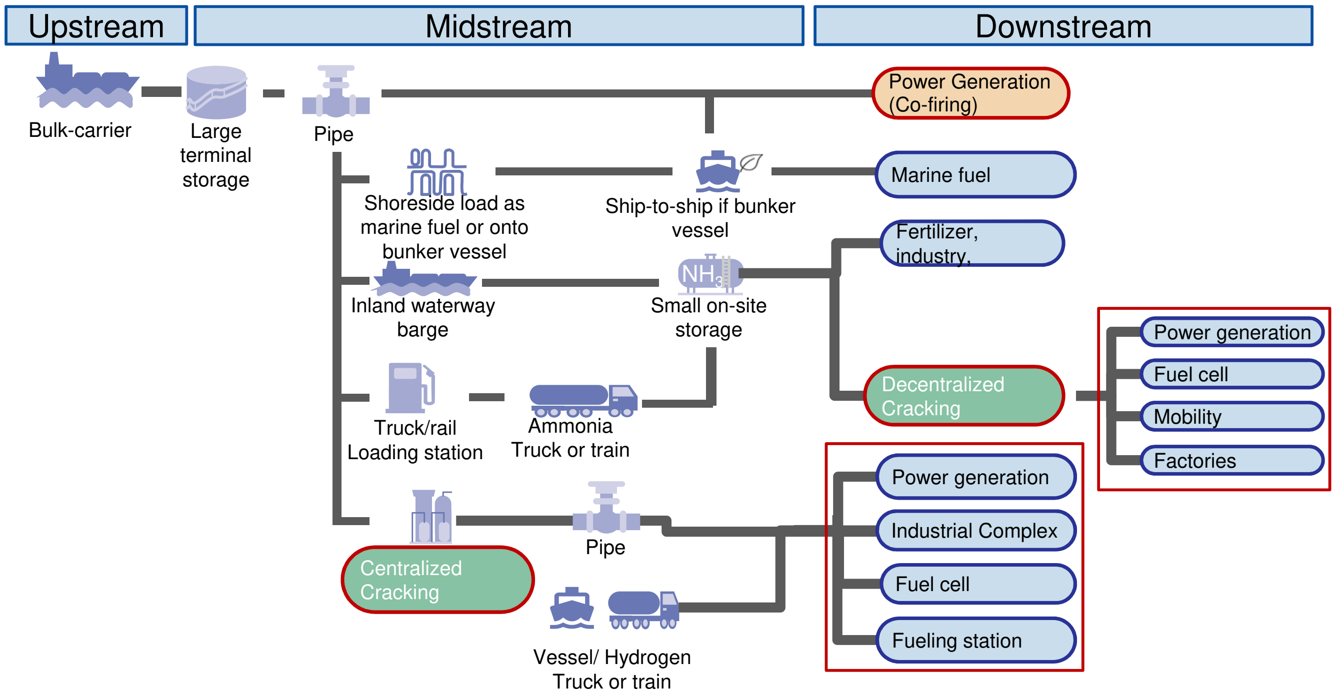
Source: Compiled by Mizuho Bank Industry Research Department

4. Export of Ammonia Supply Chain

Business Model for Global Expansion

- An ideal business model for international expansion encompasses the entire value chain, including upstream (fuel supply), midstream (transportation, storage, and cracking), and downstream processes, such as co-firing. This approach is effective in meeting local demand for hydrogen and ammonia, utilizing only ammonia as the carrier
- The co-firing of ammonia in power generation accounts for the highest volume of ammonia usage. Therefore, countries that rely heavily on coal-fired power generation should be considered high priority. In addition, cracking can be expanded after co-firing once ammonia can be procured stably

Ideal Foreign Expansion Business Model



Note: On February 23, 2024, JBIC Chairman Masafumi Maeda stated in an interview with the Nikkei Shimbun, 'Incorporating India into AZEC will lead to regional expansion. It will also establish a system that represents the voice of Asia in dialogue with the West."
Source: Compiled by Mizuho Bank Industry Research Department

Power Generation by Source around the World（Stated Policies Scenario）

- As of 2022, the Asia Pacific region has the highest reliance on coal-fired power (57%) in the world. The dependence on coal is expected to decrease by half by 2035, but the percentage of coal thermal power is still anticipated to be the highest in the world (29%)

Global Breakdown of Power Generation by Source

		Renewables	Nuclear	H2 and NH3	Fossil fuels with CCUS	Unabated coal	Unabated natural gas	Oil
North America	2022	27%	16%	0%	0%	18%	37%	2%
	2035	61%	14%	0%	0%	1%	23%	0%
Central and South America	2022	73%	2%	0%	0%	4%	15%	6%
	2035	81%	3%	0%	0%	1%	13%	2%
Eurasia	2022	19%	15%	0%	0%	20%	46%	1%
	2035	24%	17%	0%	0%	12%	47%	0%
Europe	2022	41%	19%	0%	0%	17%	21%	1%
	2035	74%	14%	0%	0%	4%	7%	0%
Middle East	2022	4%	2%	0%	0%	0%	72%	22%
	2035	19%	3%	0%	0%	0%	67%	11%
Africa	2022	24%	1%	0%	0%	28%	42%	6%
	2035	50%	2%	0%	0%	10%	33%	4%
Asia Pacific	2022	27%	5%	0%	0%	57%	10%	1%
	2035	56%	7%	0%	0%	29%	7%	0%

Source: Compiled by Mizuho Bank Industry Research Department based on IEA, World Energy Outlook 2023

The Necessity of Zero-Emission Thermal Power in ASEAN and India

- As of 2022, India, China and ASEAN have the highest reliance on coal-fired power (72%, 62%, 43% respectively) among the Asia Pacific region. By 2035, the share of coal thermal power, especially in ASEAN and India, is still anticipated to be the highest in the world, exceeding 30%
- Zero-emission thermal power in ASEAN and India plays very important role in the transition of power sector due to the limitation of infrastructure and the other power sources, the significant increase in demand, and undergoing depreciation of coal thermal power plants

Power Generation by Source in the Asia Pacific Region (STEPS Note)

		Renewables	Nuclear	H2 and NH3	Fossil fuels with CCUS	Unabated coal	Unabated natural gas	Oil
China	2022	30%	5%	0%	0%	62%	3%	0%
	2035	63%	6%	0%	0%	28%	3%	0%
Japan	2022	22%	6%	0%	0%	32%	35%	5%
	2035	48%	20%	2%	0%	14%	15%	0%
India	2022	23%	3%	0%	0%	72%	2%	0%
	2035	49%	6%	0%	0%	42%	3%	0%
ASEAN	2022	28%	0%	0%	0%	43%	28%	1%
	2035	38%	0%	0%	0%	35%	26%	1%
Other Asian Countries	2022	20%	15%	0%	0%	35%	31%	0%
	2035	45%	15%	2%	0%	18%	20%	1%

Note: Stated Policies Scenario
Source: Compiled by Mizuho Bank Industry Research Department based on IEA, World Energy Outlook 2023

The Necessity of Co-firing Power in ASEAN and India

Limited Infrastructure	• There are numerous islands in Malaysia, Indonesia, the Philippines, and on the mainland, grid coverage is limited • The interconnectivity between grids is weak
Limited Other Power Sources	• RE resources are unevenly distributed • Nuclear power are deployed limitedly • The pipeline infrastructure for LNG is limited. LNG is low uptake (except Singapore and Thailand)
Electricity Demand	• Between 2011 and 2021, the compound annual growth rate (CAGR) for the ASEAN10 was 5.0%, followed by India at 4.4%, whereas Japan experienced a negative CAGR
Coal Thermal Power	• Many relatively new coal thermal power plants are still undergoing depreciation because coal thermal power has significantly increased over the past two decades

No single power source fully meets the three essential criteria (environment, economy, and secure supply). To guarantee a stable electricity supply, thermal power technology is essential
⇒The transition may begin with coal and ammonia co-firing to zero-emission thermal power

Source: Compiled by Mizuho Bank Industry Research Department based on METI's public information

Industry Research Department　Natural Resources & Energy Team　Tran Nguyen　nguyen.a.tran@mizuho-bk.co.jp

Mizuho Short Industry Focus／229

Published July 29, 2024

Edited / issued by Industry Research Department Mizuho Bank, Ltd　1-3-3 Marunouchi, Chiyoda-ku, Tokyo　ird.info@mizuho-bk.co.jp