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Outlook for the Global Hydrogen Market Based on Decarbonization Trends

Exploring Business Opportunities for Japan

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Industry Research Department
Mizuho Bank

Summary

- Hydrogen is expected to see a global increase in demand as an essential energy source for decarbonization. However, the market is still in its infancy, with Japan expected to demonstrate its presence by leveraging its technological capabilities. In a report published in 2023* we conducted a forecast of Japan's hydrogen supply and demand and provided a cost analysis. This document, acting as a sequel, considers the process of implementing hydrogen in society based on the supply and demand forecasts of major countries and industries. It organizes the fields where Japan has a technological advantage, analyzes what business opportunities exist for Japan, and examines the measures needed to capture these business opportunities.
- In this document, we focus on power generation, automobiles, SAF (Sustainable Aviation Fuel), steel and shipping as key industries that will generate new demand. The hydrogen demand outlook, which adds new demand in major countries and industries to existing demand, is expected to be 111-118 million tons/year by 2030 and 301-430 million tons/year by 2050. The process of social implementation is predicted to vary by region.
- The total amount of global clean hydrogen production projects currently announced is about 80 million tons/year by 2030 and about 90 million tons/year by 2050. To match the capacity of supply in 2030, it is necessary to utilize clean hydrogen not only for new demand but also for existing demand.
- Japan possesses numerous technological advantages across the entire hydrogen supply chain, from upstream to downstream. To succeed in both technology and business, it is hoped that Japan will adapt to the characteristics of each region when promoting the implementation of hydrogen in society, and disseminate the technologies it excels in. From the perspective of industrial promotion, it is important for Japanese companies to expand their hydrogen handling volume and strengthen their influence in the global market. However, there are challenges in commercializing hydrogen-related technologies and expanding hydrogen handling volumes. To overcome these challenges, business segmentation and the creation of hydrogen portfolio players may be necessary.
- Additionally, to increase influence as a hydrogen demand country, a domestic market must be created at an early stage. This step requires measures such as accelerating supply chain construction through land acquisition by the government, supporting second-mover and later businesses, and refining services to improve the convenience of hydrogen utilization by businesses. It is also necessary to maximize domestic hydrogen production as a means of ensuring energy security.
- By uniting the government and related businesses to capture global hydrogen demand and promote hydrogen-related technologies, Japan can capture business opportunities surrounding hydrogen.

Note: For details, please refer to Mizuho Bank's "How Japan Can Win the Global Race for Hydrogen: Mizuho's vision for a hydrogen supply and demand structure" in "Mizuho Industry Focus Vol.237" (February 14, 2023).
Source: Compiled by Industry Research Department, Mizuho Bank, Ltd.

1. Introduction

Hydrogen: An indispensable area for decarbonization where Japan possesses technological advantages

- The fossil fuels that Japan has traditionally used as its main energy source have largely depended on other countries in terms of rights and technology. While domestic capacity for renewable energy has been expanding in recent years, suitable sites are limited, and other countries have an advantage in terms of materials.
- Hydrogen is expected to be the key to decarbonization. However, its large-scale use is just beginning, providing Japan with an opportunity to demonstrate its presence in this field.

The historical background and the current business environment of major energy sources

	Historical Background	Current Business Environment	CO_2 Emissions Per Unit During Use
Coal	• Industrial use began in the early 18th century. Domestic coal mines were also created. • With the spread of oil and the influx of overseas coal, domestic coal mines closed as demand decreased.	• Upstream development is dominated by overseas resource majors, with some interests held by Japanese companies such as electric power companies and steel manufacturers.	2.33 kg-CO_2/kg (24.3 kg-CO_2/GJ)
Oil	• Widespread use as an energy source began in the 1900s. • Before World War II, much of the demand was met by domestic crude oil. • Post-war efforts to secure overseas self-developed crude oil included the establishment of the Japan Petroleum Development Corporation. • The 1970s energy crisis spurred efforts to move away from oil.	• Upstream development is dominated by Western oil majors and national oil companies, with some interests held by Japanese oil companies and trading houses. • The self-development ratio is 33.4% when combined with natural gas.	2.67 kg-CO_2/kl (19.0 kg-CO_2/GJ)
Natural gas (LNG)	• City gas use began with oil and coal-based sources, later transitioning to natural gas. • Japan globally pioneered the introduction of LNG in 1969.	• Japanese companies hold certain strengths in plant EPC, LNG ship operations, and power generation turbines. • Upstream development is dominated by Western oil majors and national oil companies, with some interests held by Japanese city gas companies and trading houses. • The self-development ratio is 33.4% when combined with oil.	2.79 kg-CO_2/kg (13.9 kg-CO_2/GJ)
Renewable energy	• The Sunshine Project and FIT system led to an increase in the introduction of solar power. • In the early 2000s, Japan was the world's largest solar cell production base.	• In Japan, since suitable sites to introduce renewable energy on land is limited, offshore wind power development has been advancing. • China is leading in solar cells, while Europe and China have a high share in large wind turbines, leaving Japan behind.	0 kg-CO_2/kWh (0 kg-CO_2/GJ)
Hydrogen	• Currently used in oil refining and industrial processes. • Amid rising momentum towards decarbonization, the need for clean energy is increasing.	• Large-scale use as an energy source is still in its infancy globally, **with no entrenched major players** (leaving room to secure upstream interests using offtake as leverage) • Japan holds multiple technological advantages from manufacturing to utilization.	0 kg-CO_2/kg (0 kg-CO_2/GJ)

→ **Hydrogen is indispensable for decarbonization and an area where Japan can demonstrate its presence through upstream development and the introduction of manufacturing-to-utilization technologies.**

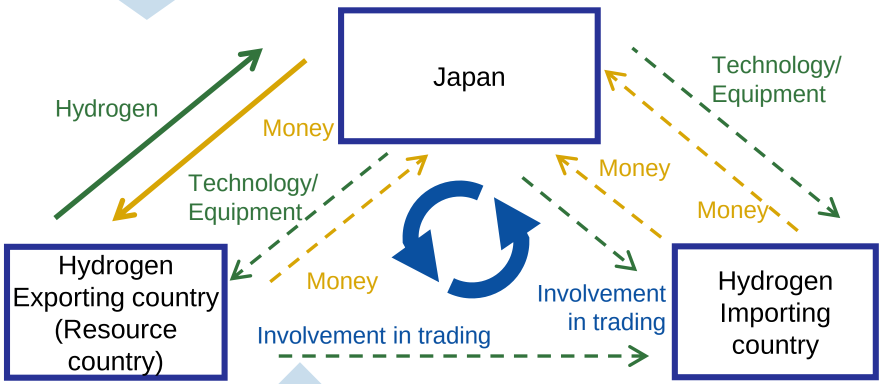
Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on data from the Agency for Natural Resources and Energy's energy white paper, the Japanese Association for Petroleum Technology's website, and the Ministry of the Environment's greenhouse gas emissions calculation, reporting, and disclosure system, etc.

This document provides an overview of global hydrogen supply and demand and examines opportunities for Japan

- As the global trend towards decarbonization accelerates, hydrogen is attracting attention as a vital energy source. To promote its industrial development, Japan needs to not only use hydrogen but also earn globally through hydrogen-related industries.
- While the uses and demand for hydrogen are expected to vary by region, this document predicts hydrogen demand in major industries globally and examines business opportunities for Japan based on regional characteristics of supply and demand.

Importance of promoting hydrogen-related industries

Japan needs to work on the early establishment of a domestic market. However, as Japan is expected to become a hydrogen importing country, just using hydrogen will result in an outflow of national wealth.



For resource countries that will be suppliers of hydrogen and other hydrogen-importing countries, Japan will develop technology and equipment for producing, transporting and storing, and using hydrogen, while also being involved in trading, thereby earning with hydrogen to achieve (1) decarbonization, (2) energy supply, and (3) economic growth, creating a "three birds with one stone" solution.

Source: Compiled by Industry Research Department, Mizuho Bank, Ltd.

Key points of this document

1. What will be the demand and supply volumes for hydrogen and ammonia in major industries and regions?
2. Where does Japan hold a technological advantage?
3. Where are the business opportunities for Japan to earn through hydrogen?

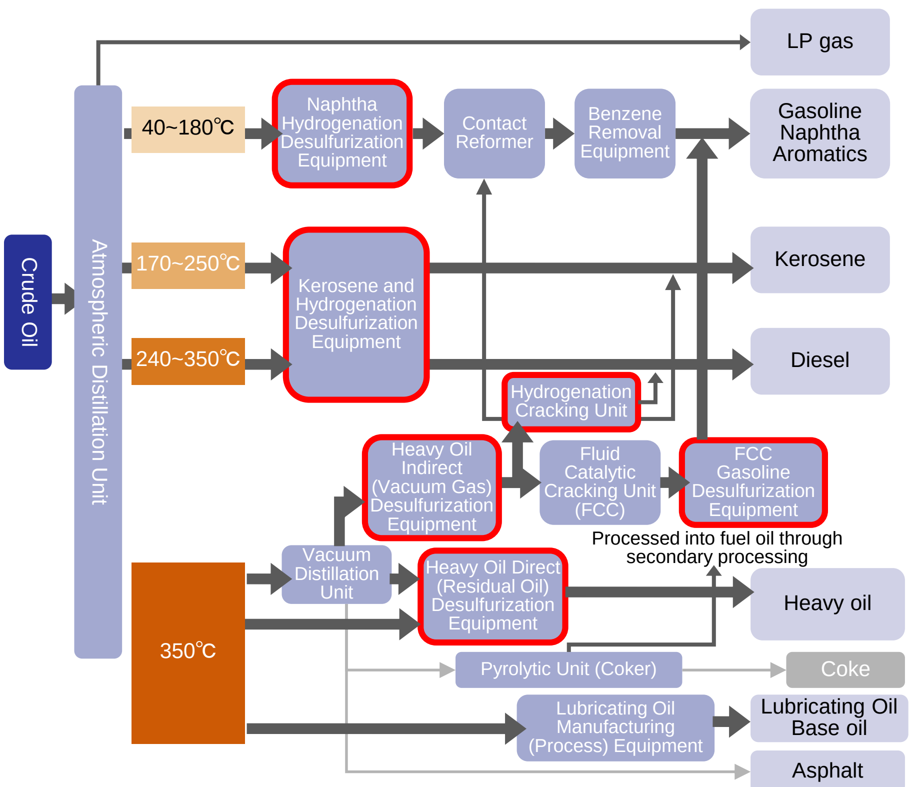
Source: Compiled by Industry Research Department, Mizuho Bank, Ltd.

2. Hydrogen Demand Outlook in Major Industries and Countries

Majority of existing hydrogen uses are in oil refining and fertilizer production

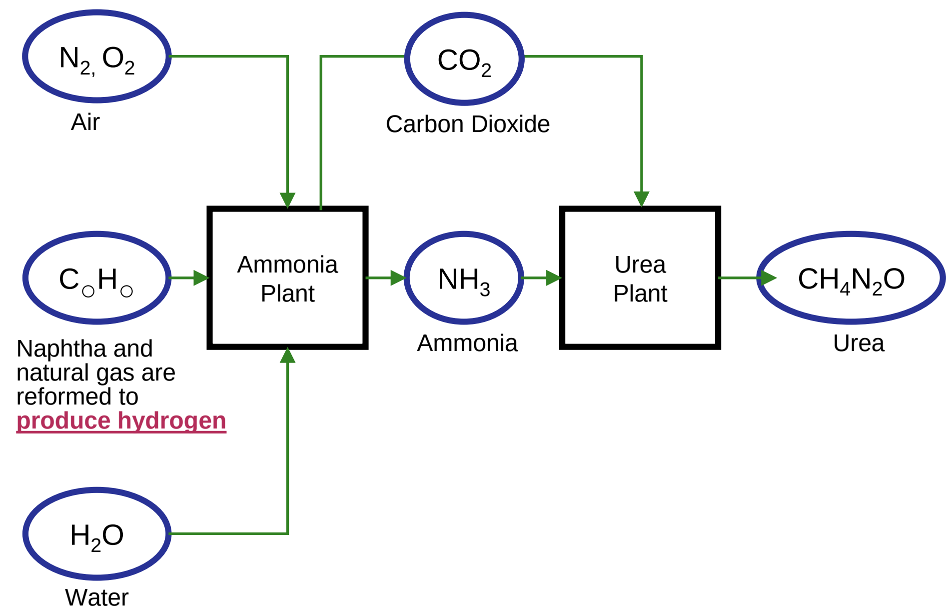
- Hydrogen is primarily used in oil refining processes and as a raw material for fertilizers.
  - In oil refining, hydrogen is used in the desulfurization process and in the hydrogenation process to upgrade product properties.
  - In fertilizer use, hydrogen is utilized as a raw material for ammonia synthesis.
- Most of the hydrogen currently consumed is gray hydrogen, which is produced with CO_2 emissions.

Hydrogen Usage in Typical Oil Refining Flow



Note: Red boxes indicate processes where hydrogen is used
Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on JOGMEC reports.

Typical Flow of Ammonia and Urea Production Used in Fertilizers

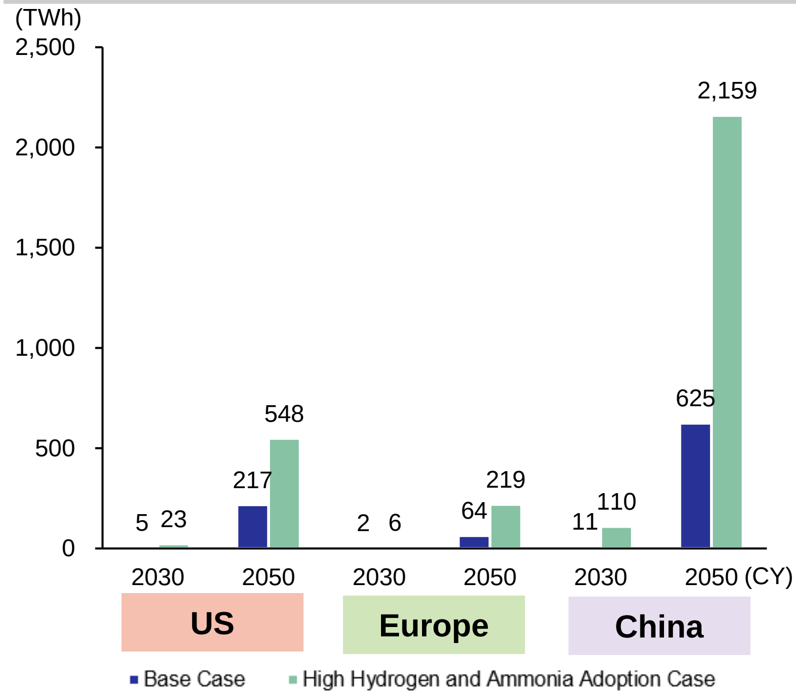


Source: Compiled by Industry Research Department, Mizuho Bank, Ltd.

To decarbonize thermal power generation, demand for hydrogen and ammonia in Europe, the US, and China is expected to increase

- To decarbonize thermal power generation, it will be necessary to use hydrogen and ammonia as co-firing or exclusive firing for power generation.
- Here we estimated volumes of hydrogen and ammonia power generation assuming the decarbonization of the power sector by 2050 in the US and Europe, and by 2060 in China.
  - A scenario was also considered where hydrogen and ammonia would be used to compensate if the introduction of renewable energy lags behind the targets (large-scale hydrogen and ammonia introduction case).
- The US and Europe, aiming to phase out coal, are not expected to utilize ammonia power generation, while China, with its high dependence on coal, is expected to utilize ammonia power generation.
  - By 2050, if each country progresses with renewable energy introduction as per their targets (base case), the required amounts in hydrogen as an equivalent are estimated to be 11 million tons in the US, 3.3 million tons in Europe, and 40.5 million tons in China.

The future potential of hydrogen and ammonia power generation



Note: Ammonia is calculated in hydrogen equivalents
Source: Both charts compiled by Industry Research Department, Mizuho Bank, Ltd.

[Mizuho's Estimate] Future required hydrogen and ammonia quantities

Approach to the future use of coal power (ammonia power generation)

	US	Europe	China
	× → No ammonia co-firing		△ → Ammonia co-firing

Power generation from hydrogen and ammonia (TWh)

	US	Europe	China
Hydrogen	2030: 5-23 2050: 217-548	2030: 2-6 2050: 64-219	2030: 1-7 2050: 179-344
Ammonia	-	-	2030: 10-103 2050: 445-1,815

Hydrogen and ammonia demand (10,000t)

The hydrogen and ammonia quantities required for power generation are calculated as follows:

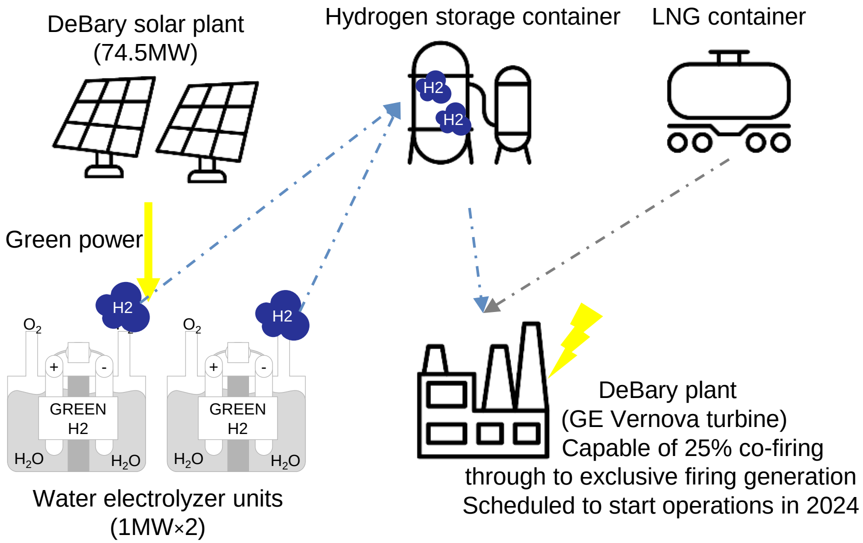
- Hydrogen: Power generation (100 million kWh) ÷ Hydrogen calorific value (120 MJ/kg) ÷ Power generation efficiency (57%)
- Ammonia: Power generation (100 million kWh) ÷ Ammonia calorific value (18.6 MJ/kg) ÷ Power generation efficiency (43%)

	US	Europe	China
Hydrogen	**2030: 28-116 2050: 1,125-2,837**	**2030: 11-26 2050: 331-1,134**	**2030: 4-35 2050: 943-1,813**
Ammonia	-	-	**2030: 463-4,627 (After hydrogen conversion: 72-717) 2050: 20,049-81,680 (After hydrogen conversion: 3,108-12,660)**

Progress in global efforts towards co-firing of hydrogen and ammonia

- Globally, efforts to implement hydrogen and ammonia power generation are progressing. For example, in the US, Duke Energy is constructing a system incorporating everything from green hydrogen production to power generation.
  - Utilizing hydrogen's storability, they plan to generate power when energy demand is high, contributing to a stable supply.
- In the APAC region, Japanese companies are moving to provide excellent co-firing technologies, aiming to contribute to emission reductions around the world.

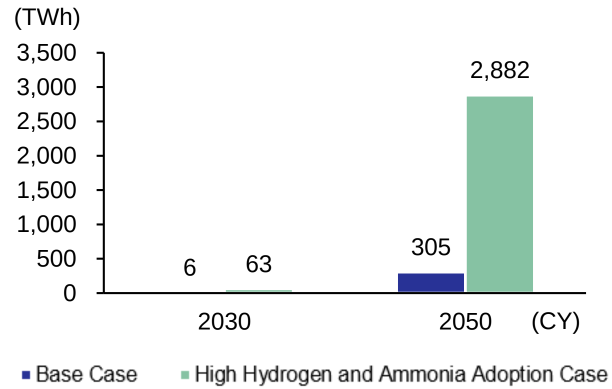
Duke Energy's demonstration of green hydrogen production, storage, and power generation



- ✓ **An end-to-end system has been established** of green hydrogen produced using clean electricity from solar power plants through to storage and power generation.
- ✓ Construction of the first exclusive **hydrogen firing power plant** in the US.
- ✓ **Utilizing hydrogen's storability**, it can **generate power during high-demand periods**, contributing to stable supply.

Note: Quoted from press release by Duke Energy on October 27, 2023.
Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on published materials.

The future potential of hydrogen and ammonia power generation in APAC (excluding China and Japan)



Hydrogen (million tons)

2030: 0.1 – 1.02
2050: 8.67 – 78.39

Ammonia (million tons)

2030: 4.63 – 46.27
(After hydrogen conversion: 0.72-7.17)
2050: 62.91 – 626.99
(After hydrogen conversion: 9.75 – 97.19)

Japanese companies provide co-firing technology to APAC companies

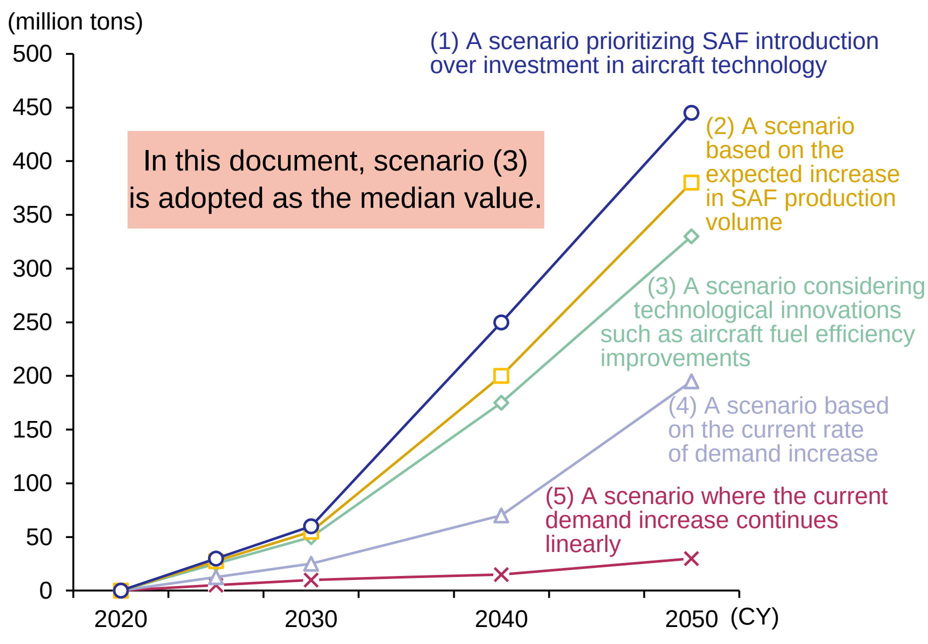
IHI Kowa	■ Technical discussions with Adani Power Ltd. have begun at the Adani Power Mundra coal-fired power plant in India, assuming 20% ammonia co-firing.
Mitsubishi Heavy Industries	■ Signed an MOU with Indonesia's PLN for technical discussions on co-firing of hydrogen, ammonia, and biomass at its power plants.

Note: APAC = Asia-Pacific (including Australia, East Asia, Southeast Asia, and Southwest Asia).
Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on published materials and other sources for both charts.

As SAF demand grows, hydrogen demand for manufacturing processes is expected to increase

- SAF usage is the main means of decarbonization in the aviation industry.
  - Although the range differs depending on the scenario, demand is expected to increase steadily.
- In this report, we estimated the hydrogen demand for SAF by considering the required hydrogen quantity for each production method, based on the median SAF demand outlook from the Air Transport Action Group (ATAG) and specific raw materials, catalysts, and production methods.

Global SAF demand outlook

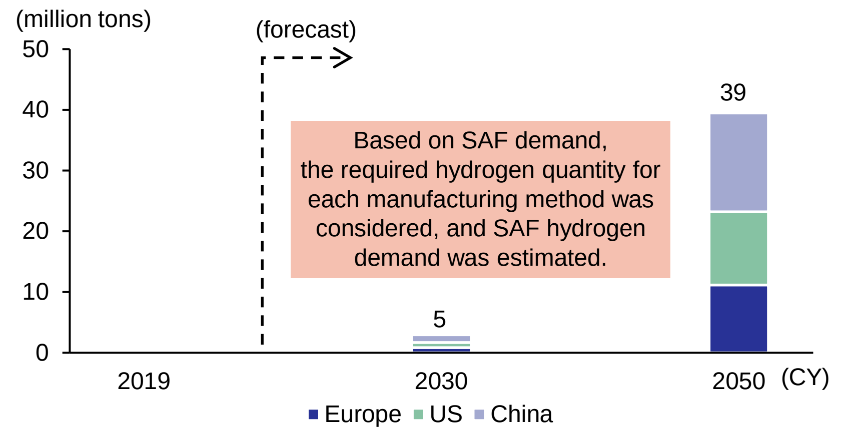


Note: SAF = Sustainable Aviation Fuel.
Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on Air Transport Action Group (ATAG), Waypoint 2050

Main SAF manufacturing methods

Main methods	Summary
HEFA (Hydroprocessed Esters and Fatty Acids)	Manufactured by hydrogenating waste cooking oil, etc.
ATJ (Alcohol To Jet)	Manufactured from ethanol via catalytic reaction
Gasification FT (Fischer-Tropsch)	Manufactured by gasifying biomass and synthesizing it into liquid fuel
Synthetic fuels	Manufactured by synthesizing green hydrogen and CO2

Outlook for hydrogen demand for SAF manufacturing



Source: Both charts compiled by Industry Research Department, Mizuho Bank, Ltd.

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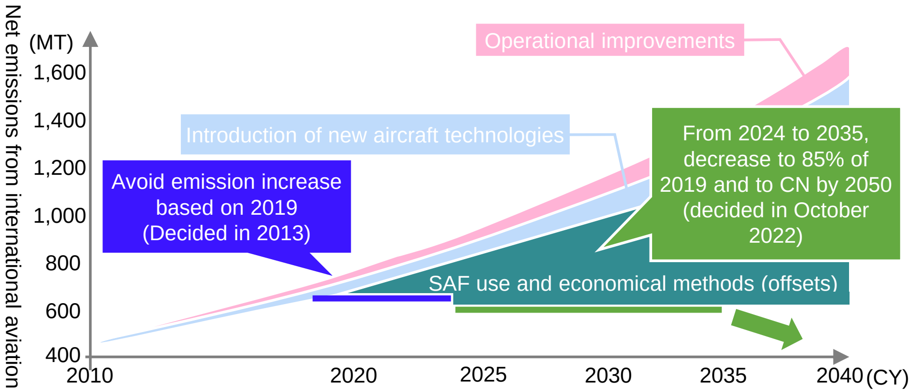
To reduce CO2 emissions, airlines worldwide are advancing SAF procurement

- The Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) started in 2021, and airlines are procuring SAF and investing in manufacturing companies.

Global regulation: Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)



Key points of target achievement applicability and GHG emissions offset system (CORSIA)

Participating countries	From 2021 to 2026: 88 countries participating voluntarily (covering about 80% of international flights, including many major developed countries such as Japan, the US, and Europe)
	From 2027 onwards: All obligated countries will participate
Applicability Operators	International operators with annual emissions exceeding 10,000 tons from aircraft with a maximum takeoff weight over 5.7 tons → Almost all major aircraft and full-service carriers are included
Applicability Routes	Applies only to routes between participating countries (regardless of the operator's nationality) → Given the range of participating countries, many major routes are included
Obligations for applicable operators	Monitor annual CO2 emissions from 2019 onwards and calculate and set the baseline (considering demand drops). The baseline for 2021-2023 is the single year of 2019, from 2024 to 2035 this will shift to 85% of 2019
	From 2021 onwards, based on notifications of the amount of carbon offsets required, emission amounts will be offset by credits or reduced via SAF usage

Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on various published materials from ICAO, IATA, etc.

Examples of SAF use by airlines

ANA	✓ Launched the SAF Flight Initiative, providing a program where member companies can partially bear the cost of SAF and receive CO2 reduction certificates ✓ SAF loaded and used in ANA's Green Jet
JAL	✓ Signed an agreement with Shell Aviation for SAF procurement, replacing the fuel loaded at Los Angeles Airport with SAF ✓ Invested in Fulcrum, a company with SAF manufacturing technology
Air France-KLM	✓ Signed SAF procurement agreements with Neste, DG Fuels, SkyNRG, and TotalEnergies ✓ Added 1% SAF to the fuel system at Amsterdam Airport Schiphol for all flights departing from the airport
United Airlines	✓ Operated the world's first passenger flight using 100% SAF from Chicago to Washington, D.C. ✓ Established Blue Blade Energy, a joint venture with energy companies to manufacture ethanol-derived SAF

Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on published information

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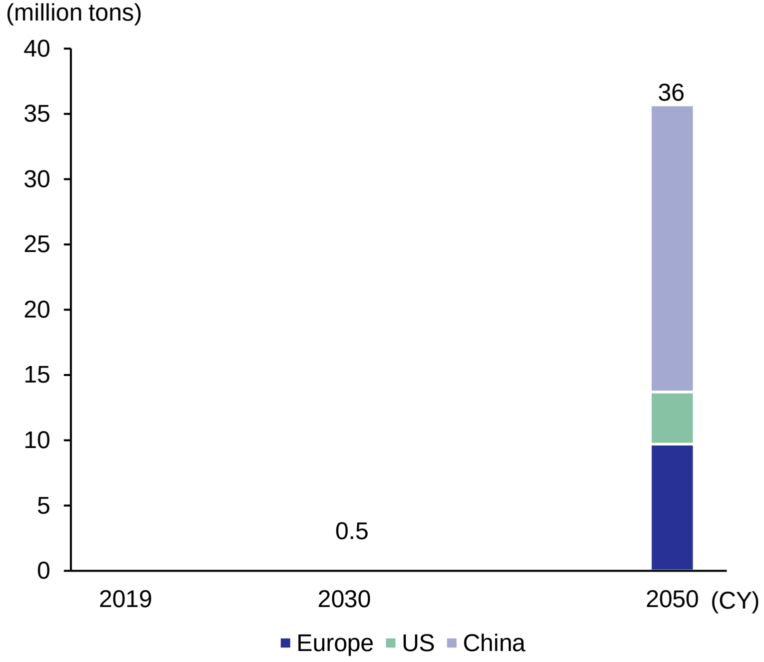
In the automotive sector, hydrogen demand is expected to increase for medium and large trucks

- In the automotive sector, while it is assumed passenger cars will primarily be converted to EVs, FCVs are seen as an effective solution for commercial vehicles in terms of long-distance driving and quick refueling compared to Evs.
- The penetration rate of FCVs is expected to vary significantly by country and region due to differences in fuel prices.
  - In Europe, where the price difference between hydrogen and electricity is assumed to be small, the penetration rate of FCVs could be relatively high.
- Hydrogen demand for medium and large trucks in major countries and regions is expected to be 0.5 million tons in 2030 and 36 million tons in 2050.

Hydrogen demand outlook for medium and large fuel cell trucks (Europe, US, China)



Note: The target is the amount of hydrogen needed for FCV (including hydrogen engine vehicles in Europe) operation among medium and large trucks in Europe, the US, and China.
Source: Compiled by Industry Research Department, Mizuho Bank, Ltd.

Sales and vehicles in use numbers of FCVs in 2030 and 2050

		2030	2050
Europe	Hydrogen demand (million tons)	0.19	9.7
	Sales volume (units)	21,330	150,146
	Sales share (%)	6%	53%
	Vehicles in use (units)	38,442	2,614,652
US	Hydrogen demand (million tons)	0.19	4.0
	Sales volume (units)	11,058	82,213
	Sales share (%)	2%	13%
	Vehicles in use (units)	35,801	868,967
China	Hydrogen demand (million tons)	0.14	22.0
	Sales volume (units)	31,661	603,791
	Sales share (%)	3%	40%
	Vehicles in use (units)	56,323	5,239,437
Total	Hydrogen demand (million tons)	0.5	35.7
	Sales volume (units)	64,049	836,150
	Vehicles in use (units)	130,566	8,720,056

Note: Hydrogen demand was calculated by multiplying the number of FCVs owned in each country/region by assumed hydrogen fuel consumption and annual mileage. The number of vehicles, hydrogen fuel consumption, and annual mileage vary by country/region.
Source: Compiled by Industry Research Department, Mizuho Bank, Ltd.

OEMs of large trucks in Europe and America are advancing ZEV deployment strategies

- Many European and American OEMs are deploying both EVs and FCVs; currently, EVs are leading in commercialization, but FCVs are expected to be introduced for long-distance driving in the future.
  - Daimler is the only OEM with a clear development policy for hydrogen engines, positioning them as a niche solution for mining, construction, etc.

European and American large truck OEMs' ZEV[1] deployment strategies

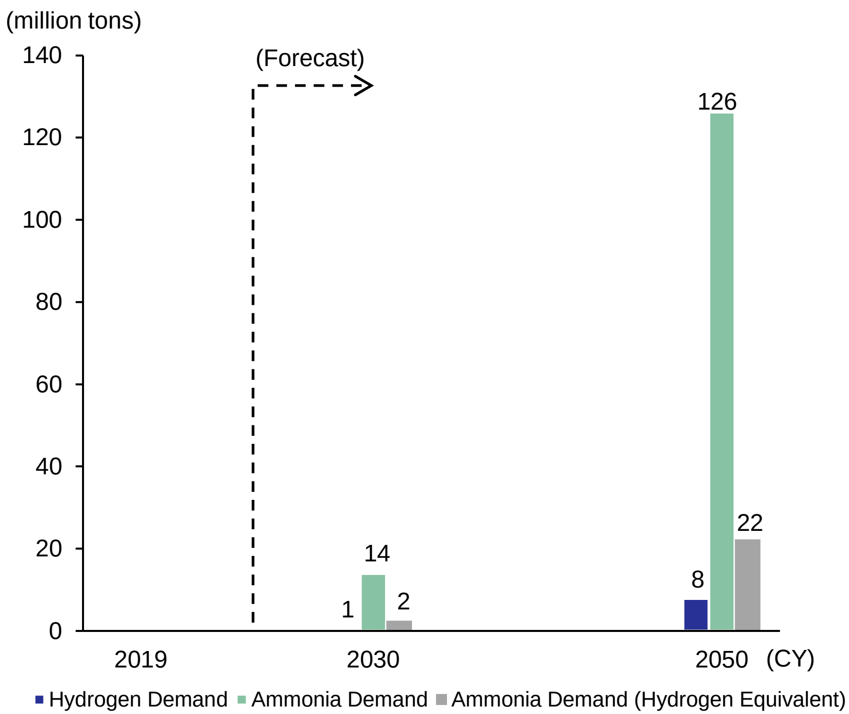
	EV	FCV	Hydrogen engine	Summary
Daimler Truck (European)	√√√ Regional transport	√√ Long-distance transport	√ Mining, construction, etc.	❑ Dual strategy positioning both EVs and hydrogen as important ZEVs ❑ EVs positioned for regional transport, FCVs for long-distance transport, and hydrogen engines as niche solutions for sectors with high-power-demand such as mining, construction, and agriculture. High running costs are mentioned as one downside of hydrogen engines. ❑ Already introducing EVs through the eActros series, with multiple lineups. ❑ FCVs, a 25-ton truck with a range of over 1,000 km (GenH2), are planned for around 2027, with trials starting in Germany with Amazon in 2024. ❑ The introduction time for tracks with hydrogen engines was not specified, but the development policy was announced in July 2023.
Volvo (European)	√√ Inter-regional and urban transport	√√ Long-distance transport	√√ Non-EV/FCV conditions, etc.	❑ Promoting electrification through three pillars: EVs, hydrogen (fuel cells and hydrogen engines), and renewable fuels. ❑ By 2040, the majority (over 80%) will be EVs and FCVs, with the rest composed of BioLNG, HVO, hydrogen engines, etc. ❑ FCVs are being positioned for long-distance transport, and EVs for inter-regional and urban transport. ❑ EVs are currently being deployed with six models in the FH series. ❑ Planning FCVs for the late 2020s, with large trucks having a range of about 1,000 km (model undecided). ❑ Announced collaboration with Canada's Westport on developing hydrogen-compatible direct injection engines.
Traton (European)	√√√ All-round	√ Long-distance, addressing charging infrastructure shortages, etc.	√ Special applications such as construction	❑ Emphasizing EV deployment for the transition to ZEVs. Highlights that EV energy efficiency surpasses FCVs (stating 75% energy efficiency from generation to driving for EVs compared to about 25% for FCVs due to energy losses in electrolysis, transportation, and refueling processes). Envisions limited use of FCVs in long-distance and areas with inadequate charging infrastructure. ❑ Already introduced EVs with Scania (P and L series) and MAN (eTruck) seeing mass production and deployment. ❑ Co-developing FCVs with Scania (its subsidiary in Europe) and Cummins, and with Navistar (its subsidiary in the U.S.) and GM. ❑ MAN, a subsidiary, plans to launch Europe's first hydrogen engine truck, the hTGX series, in 2025.
Paccar (American)	√√√ Inter-regional, urban, and port transport	√√ Long-distance transport	N/A No strategic mention	❑ Since 2021, has started commercializing EV trucks, and has a line up of nine models mainly for inter-regional, urban, and port transportation uses. ❑ Positions FCVs, with their long driving range and relatively short refueling time, as a promising powertrain for long-distance use. ❑ They are advancing joint development of FCVs with Toyota, planning to start sales as early as 2024 and aiming for mass production by 2025.

Note 1: ZEV = Zero Emission Vehicle, a vehicle that does not emit CO_2 or other exhaust gases while driving.
Note 2: Check counts are assigned qualitatively evaluating each company's commitment to different powertrains based on publicly available information and IR materials (the more checks, the more proactive).
Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on IR materials

In the shipping sector, the IMO's targets are expected to boost hydrogen and ammonia demand

- In the shipping sector, due to the International Maritime Organization's (IMO) advancement of the net-zero target, it is necessary to switch fuels from oil to CN fuel by 2050.
- Assuming certain energy demands and proportions of energy used in the shipping sector, it is estimated that by 2030, hydrogen demand will be 1 million tons and ammonia demand will be 14 million tons in Europe, the US, and China—by 2050, hydrogen demand will be 8 million tons and ammonia demand will be 126 million tons.

Hydrogen and ammonia demand outlook for shipping in Europe, the US, and China

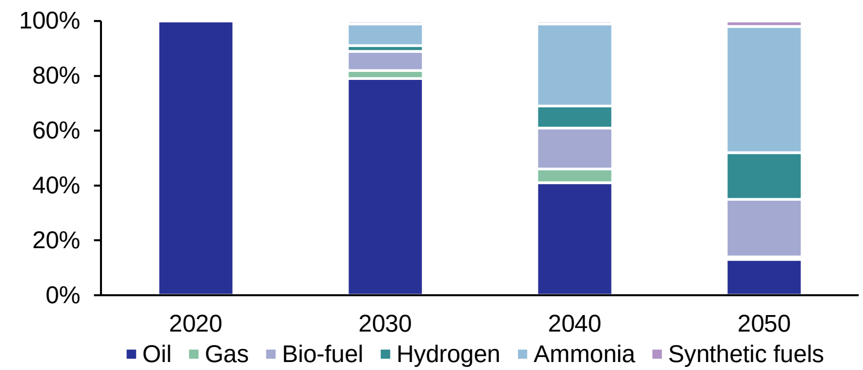


Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on IEA, World Energy Balances and Net Zero by 2050.

Calculation method

- ✓ We forecast the total demand for the global shipping sector assuming per capita energy demand remains constant and predicting future population
- ✓ We calculated the global hydrogen and ammonia demand in the shipping sector using the fuel usage ratios in the IEA's NZE scenario
- ✓ The calculated values are apportioned by GDP ratio to derive the demand in Europe, the US, and China.

Fuel usage ratios in the shipping sector in the IEA NZE(*)



Note: NZE: Net Zero Emission Scenario, a scenario in which global greenhouse gas emissions reach net zero by 2050.
Source: Both charts compiled by Industry Research Department, Mizuho Bank, Ltd. based on the IEA and Net Zero by 2050.

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In the shipping industry, fuel switching is being considered as a means of decarbonization

- In July 2023, the IMO revised its GHG reduction strategy, adopting a goal to achieve net-zero GHG emissions from international shipping by around 2050.
- Achieving CN requires fuel switching, with ammonia expected to be a zero-emission fuel for international shipping.

Revisions to the IMO's GHG reduction targets

<IMO GHG Reduction Strategy (2018 version)>

Target year	Content
2030 (Compared to 2008)	✓ At least 40% improvement in transport efficiency
2050 (Compared to 2008)	✓ At least 70% improvement in transport efficiency ✓ At least 50% reduction in total GHG emissions
By the end of this century	✓ Zero GHG emissions

Revised in July 2023

<IMO GHG Reduction Strategy (2023 version)>

Target year	Content
2030 (Compared to 2008)	✓ At least 40% improvement in transport efficiency ✓ At least 20% reduction in total GHG emissions (aiming for 30% reduction) ✓ At least 5% adoption of zero-emission fuels (aiming for 10% adoption)
2040 (Compared to 2008)	✓ At least 70% reduction in total GHG emissions (aiming for 80% reduction)
Around 2050	✓ Net zero GHG emissions

Shipping companies' approach

While energy-saving technologies (e.g., wind propulsion) and operational efficiency improvements are also important, achieving CN requires fuel switching.

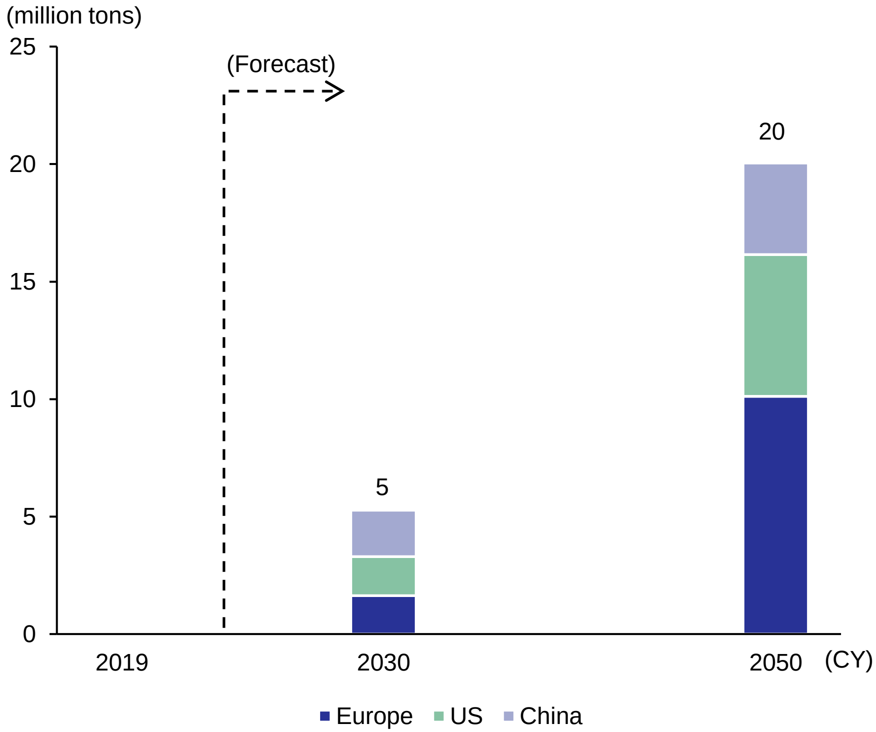
Country	Approach
Japan	**LNG → Methanol, Ammonia considerations** ✓ Mitsui O.S.K. Lines: 90 LNG/methanol-fueled ships (by 2030), 130 zero-emission ships (by 2035) ✓ Nippon Yusen: 31 LNG-fueled ships, 3 ammonia-fueled ships, 8 LPG-fueled ships, 3 methanol ships (FY2023-FY2030), 12 ammonia-fueled ships, 7 LNG-fueled ships (FY2031-FY2033) ✓ K Line: 20 zero-emission ships (by 2030), 130 zero-emission ships (by 2040), 200-250 zero-emission ships (by 2050)
Global	Similar direction as Japanese shipping companies, **but like Maersk, LNG is not introduced, and some companies increase methanol and ammonia-fueled ships** ✓ Maersk: Over 200 zero-emission ships (by 2026)

Source: Both charts compiled by Industry Research Department, Mizuho Bank, Ltd. based on various published materials.

In the steel sector, hydrogen demand is expected to increase with the expansion of hydrogen reduction steelmaking

- In the steel sector, traditional reduction of iron ore using coal or gas has been conducted, but to achieve low/decarbonization, the reducing agent is being switched from fossil fuels to hydrogen. In Europe, the US, and China, hydrogen demand for this usage is expected to reach a total of 20 million tons by 2050.
- In particular Europe is expected to see a dramatic increase in hydrogen reduction steelmaking (hydrogen reduction furnaces + electric furnaces), creating significant hydrogen demand.

Hydrogen demand outlook in the steel sector (Europe, US, China)



Source: Compiled by Industry Research Department, Mizuho Bank, Ltd.

Assumptions

	Year	Crude steel production (million tons)	Electric furnace ratio (%)	Hydrogen demand (Ten thousand tons)
Europe	2030	154	52	142
	2050	165	100	1,125
US	2030	100	75	109
	2050	131	81	465
China	2030	1,003	25	169
	2050	898	43	239

Source: Compiled by Industry Research Department, Mizuho Bank, Ltd.

European companies leading with direct hydrogen reduction technology, Japan announces accelerated development of hydrogen reduction technology

- In June 2022, Japan's three major blast furnace companies formed a hydrogen steel consortium, aiming to share information on CN technology, develop and use it across companies. However, European companies are somewhat ahead with direct hydrogen reduction technology (other countries like China and South Korea are also advancing their development of this technology).
- In response to this situation, a roadmap revision (accelerating technology development by 2-5 years) and an increase in the allocation of the GI Fund (+256.4 billion yen) were presented at the 18th Industrial Structure Council in September 2023. To ensure that the domestic steel industry does not lose competitiveness, it is necessary to continue efforts that maintain pace with overseas companies in the speed of technology development and to enhance competitiveness in the procurement costs of hydrogen and electricity.

Examples of hydrogen reduction technology development by overseas companies

Europe / Arcelor Mittal

- ✓ Building a direct hydrogen reduction demonstration plant in Germany, scheduled to start operation by the end of 2025
- ✓ Other DRI plants and electric furnaces are being newly constructed mainly in Germany and France.

Europe / Thyssenkrupp

- ✓ Started the H2Stahl project for the development of both blast furnace hydrogen reduction and direct hydrogen reduction technologies
- ✓ Plans to build a DRI plant with a capacity of 1.2 million tons/year by around 2025

China / Baowu Steel Group

- ✓ Started research on hydrogen reduction using a small blast furnace at Bayi Iron and Steel (scheduled to operate by the end of 2024)
- ✓ Decided to build a DRI plant with a capacity of 1 million tons/year at the Zhanjiang Iron and Steel (scheduled to operate in 2024)

South Korea / POSCO

- ✓ Advancing the development of HyREX, a direct hydrogen reduction technology using its unique steelmaking technology "FINEX"

Note: DRI: Direct Reduced Iron, iron produced by directly reducing iron ore with reducing gas

Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on a variety of materials.

Formation of a cross-company consortium in Japan for decarbonization

Hydrogen Steel Consortium (established June 2022)

Nippon Steel / JFE Steel / Kobe Steel / JRCM(1)

GI Fund from 193.5 billion yen to 449.9 billion yen (increase)

Information sharing/joint technology development and use

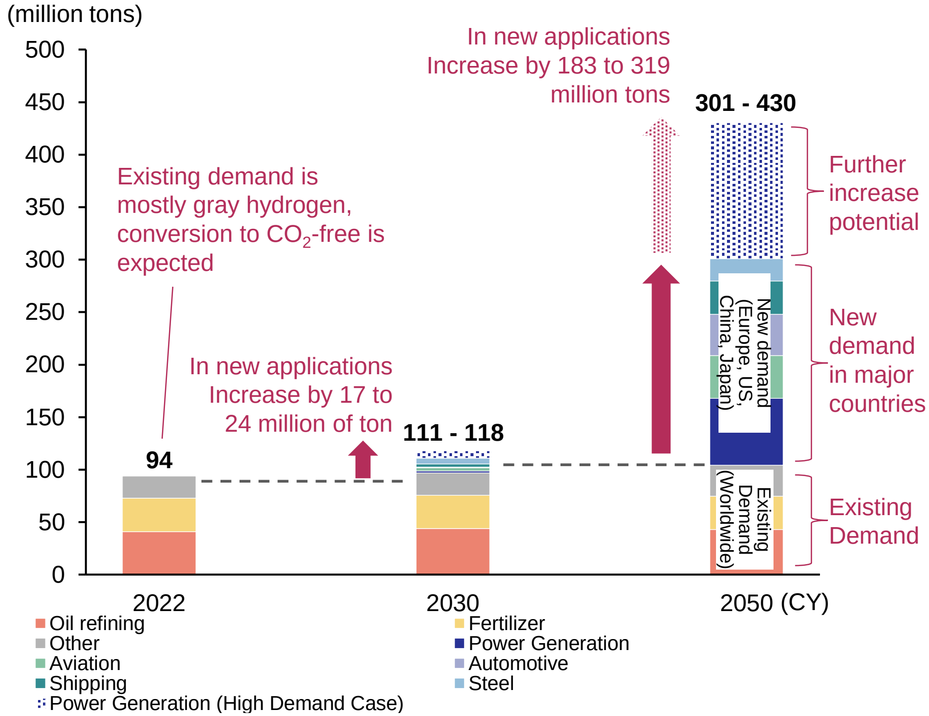
		[Technology development content]	[Furnace used]	[Overview of roadmap revision plan]	[Budget revision plan]
Blast furnace hydrogen reduction	①	Development of hydrogen reduction technology utilizing internal hydrogen (COURSE50)	Blast furnace + converter	Real demonstration test to start in the second half of 2025 Aiming for technology implementation **by 2028**	43.6 billion yen (+29.6 billion yen)
	②	Development of low-carbon technology utilizing external hydrogen and blast furnace gas (Super COURSE50 / CR blast furnace(2))	Blast furnace + converter	Element technology development by 2025, Test start at a small-scale test blast furnace Aiming for technology implementation **by 2040**	238.6 billion yen (+117.2 billion yen)
Direct hydrogen reduction	③	Development of direct hydrogen reduction technology	Hydrogen reduction blast furnace + large electric furnace	Element technology development by 2025, Test start at a small-scale test furnace Aiming for technology implementation **by 2040**	114.1 billion yen (+79.6 billion yen)
	④	Development of impurity removal technology for electric furnaces using directly reduced iron	(Hydrogen reduction furnace) + large electric furnace	Element technology development by 2025, Small-scale test electric furnace test Aiming for technology implementation **by 2030**	30.6 billion yen (+7 billion yen)
	⑤	Development of hydrogen reduction technology using an electric smelter	(Hydrogen reduction furnace) + smelter + converter	Mid-scale test electric furnace test around 2026 Aiming for technology implementation **by 2030**	23 billion yen **(Newly added)**

Note 1: JRCM = Japan Research and Development Center for Metals
Note 2: CR blast furnace = Carbon Recycling Blast Furnace
Note 3: Kobe Steel is not participating in ③ Note 4: ④⑤ include considering importing hydrogen reduced iron from overseas
Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on materials from the Hydrogen Steel Consortium and the Ministry of Economy, Trade and Industry.

Global hydrogen demand in major industries and regions is expected to expand in leadup to 2050

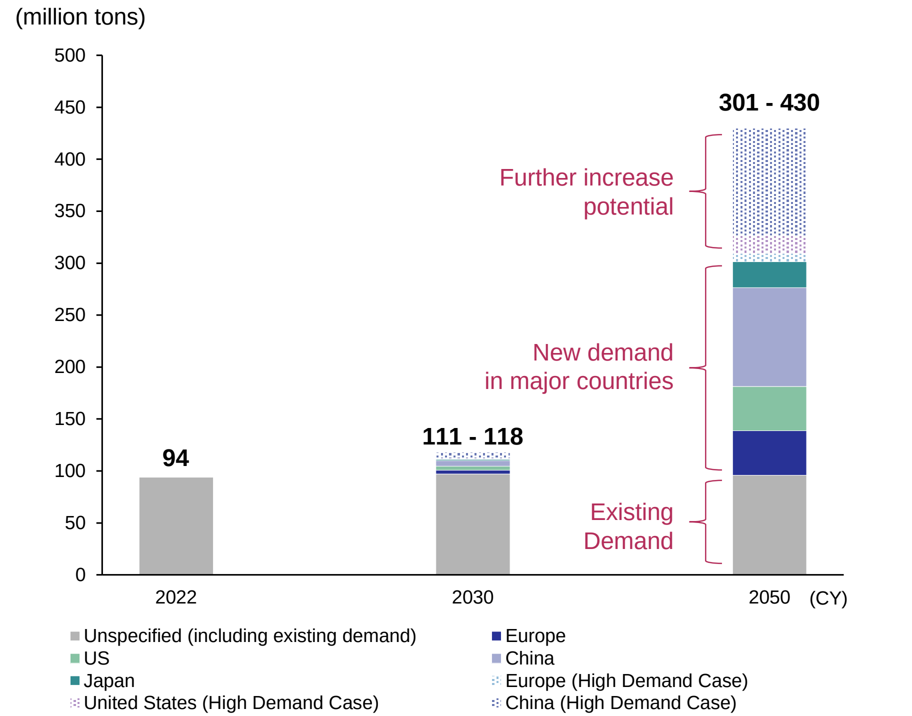
- Hydrogen is already used in oil refining and fertilizer production, but its demand is expected to expand driven by new applications aimed at low/decarbonization towards 2050.
- The key to expanding demand is converting existing uses to CO_2-free hydrogen and promoting the use of CO_2-free hydrogen in new applications. There are also potential upsides in natural gas energy alternatives and fuel cells.

Global hydrogen demand outlook by application in major industries and regions



Note: Besides existing demand (oil refining, fertilizers, etc.), the estimates focus on industries and regions with a high probability of hydrogen use and do not predict the total global demand at each point in time.
Source: Compiled by Industry Research Department, Mizuho Bank, Ltd.

Global hydrogen demand outlook by region in major industries and regions



Note 1: Besides existing demand (oil refining, fertilizers, etc.), the estimates focus on industries and regions with a high probability of hydrogen use and do not predict the total global demand at each point in time.
Note 2: "Unspecified" includes existing uses and shipping uses.
Source: Compiled by Industry Research Department, Mizuho Bank, Ltd.

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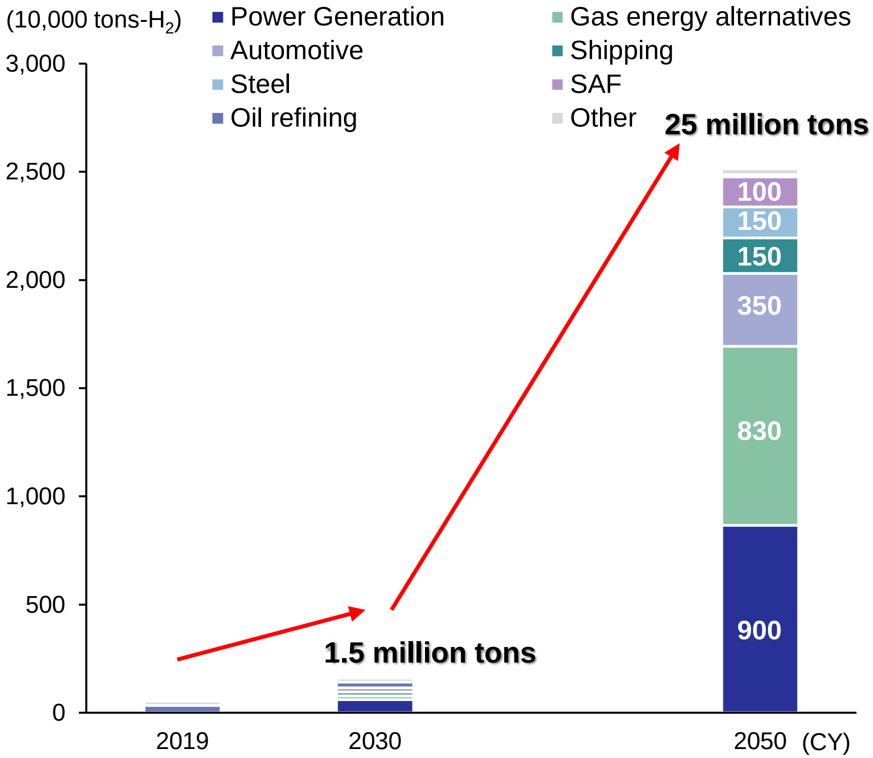
[Reference] Domestic hydrogen demand outlook in leadup to 2050

- In Japan, by 2050, the demand for hydrogen is expected to reach around 25 million tons when considering not only power generation, steel, and automotive industries but also other industries with potential demand.
  - Domestic hydrogen demand in 2050 is expected to be centered around power generation, gas energy alternatives, automobiles, shipping, steel, and SAF.
- As 2050 approaches, the demand will grow rapidly in a tail-heavy manner, and the demand in 2030 is expected to be lower compared to the EU and other regions.

Demand outlook for externally sourced hydrogen (by application, approximate numbers)



Note: Taken from Mizuho Bank's "How Japan Can Win the Global Race for Hydrogen: Mizuho's vision for a hydrogen supply and demand structure" in "Mizuho Industry Focus Vol.237" (February 14, 2023), with forecasts about SAF demand added.
Source: Compiled by Industry Research Department, Mizuho Bank, Ltd.

Key points of demand outlook through to 2050

SAF	• Hydrogen demand for SAF production is expected to expand as jet fuel is replaced by SAF
Steel	• By partially transitioning from blast furnaces using coal to SuperCOURSE50 carbon recycling blast furnaces and hydrogen reduction steelmaking, demand will emerge for externally procured hydrogen
Shipping	• Hydrogen and ammonia demand will emerge due to the conversion to hydrogen and ammonia-fueled ships
Automotive	• A partial shift from gasoline and diesel vehicles to FCVs is expected. • Particularly significant demand increase from fuel cell trucks and buses
Gas energy alternatives	• According to the Japan Gas Association, the plan is to inject 1% synthetic methane into pipelines by 2030 and 90% by 2050 Assumption of 5% direct hydrogen supply in 2050
Power Generation	• According to the Strategic Energy Plan, hydrogen and ammonia power generation will account for 1% of the power supply in 2030 • By 2050, it is estimated that hydrogen and ammonia exclusive firing will make up 13% of the power supply composition

Source: Compiled by Industry Research Department, Mizuho Bank, Ltd.

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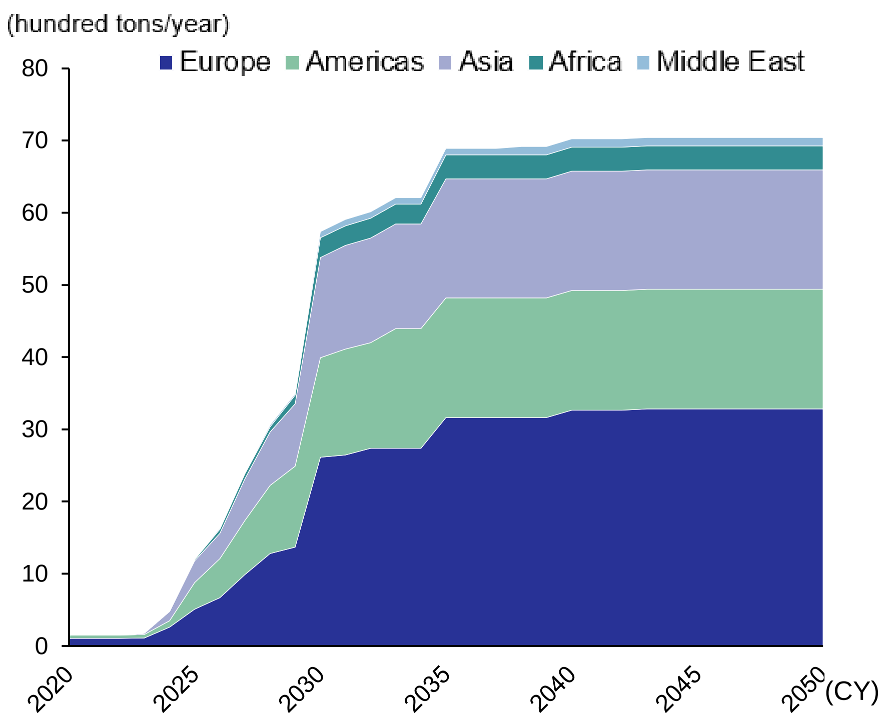
3. Global hydrogen supply outlook

Hydrogen manufacturing projects are beginning to accumulate, but few have reached FID

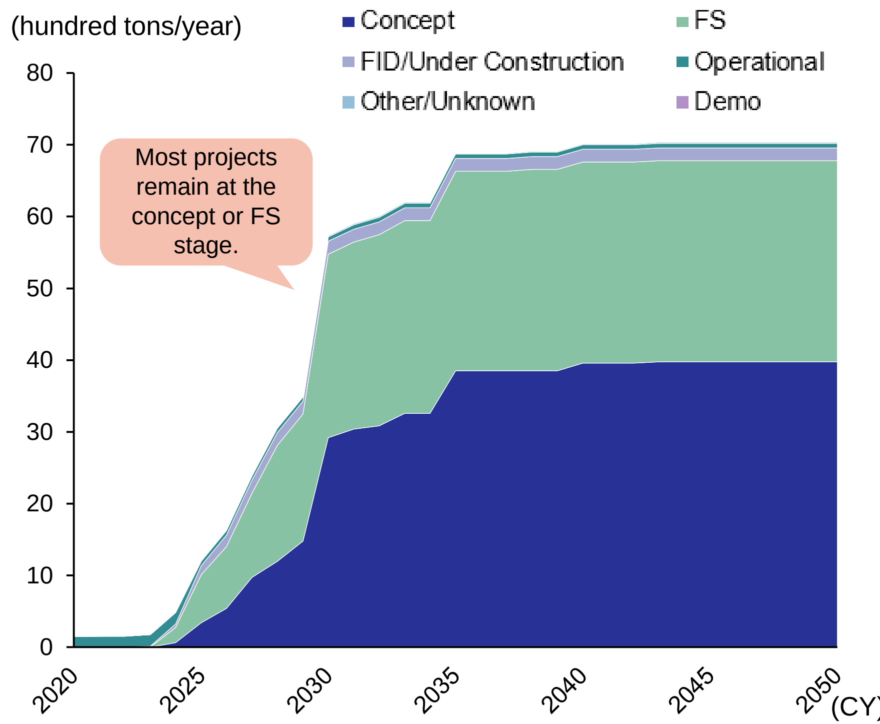
- The scale of clean hydrogen manufacturing projects expected to operate from 2020 onwards (excluding those with unknown operation timing) is about 60 million tons by 2030.
  - On the other hand, projects at FID, under construction, or operating will only be at about 1 million tons by 2030.

Trends in regional manufacturing capacity of clean hydrogen projects



Note 1: Accumulation of projects from 2020 onwards
Source: Both charts compiled by Industry Research Department, Mizuho Bank, Ltd. based on IEA, Hydrogen Projects database (October 2023)

Trends in manufacturing capacity by status of clean hydrogen projects

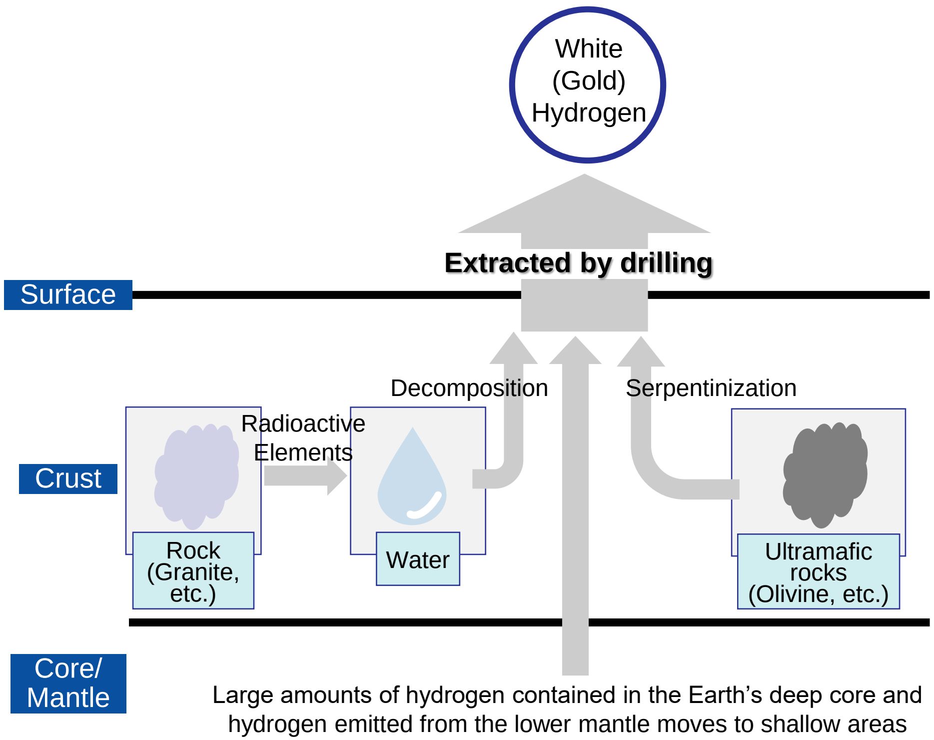


Note 1: FID: Final Investment Decision
Note 2: FS: Feasibility Study

[Reference] Attention is also being paid to natural hydrogen accumulated underground

- Natural hydrogen is hydrogen that has naturally accumulated underground, with initial estimates suggesting it is a source with the potential to exceed current demand.
  - It accumulates from rock formations and eruptions from the deep earth and is called white hydrogen or gold hydrogen.
- No examples exist of commercial development, but there are several exploration and development projects by government agencies and startups.

Overview of natural hydrogen



Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on JOGMEC's "Natural Hydrogen Trends"

Major natural hydrogen production projects

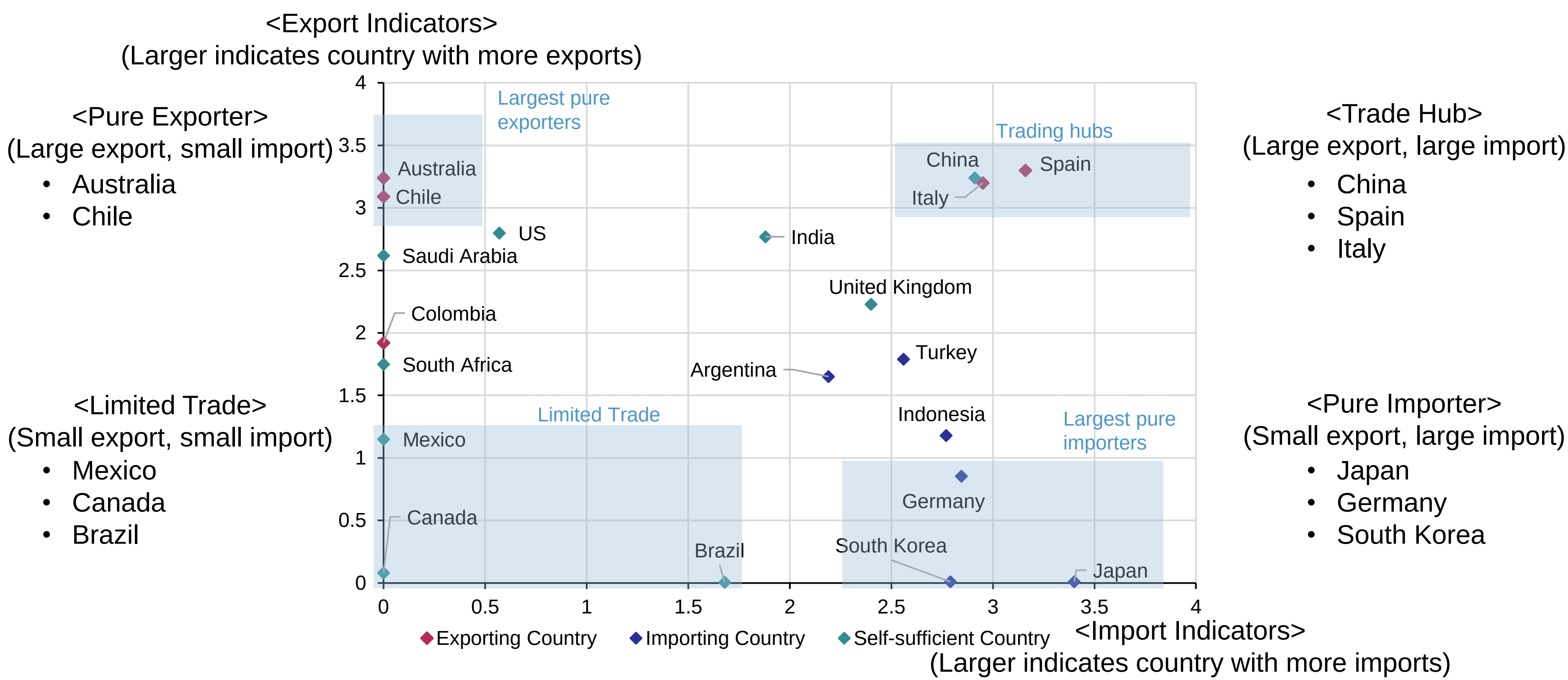
Country	Location	Developer	Status
Australia	York Peninsula	Gold Hydrogen	Drilling permit obtained. Exploration from October 2023
Australia	Eyre Peninsula	H2EX	Permit obtained
Australia	Amadeus Basin	Santos	Test drilling for evaluation of reserve
France	Lorraine Basin	La Française De l'Énergie	Application for exclusive exploration permit
Mali	Bourakebougou	Hydroma	Operational since 2012
Spain	Pyrenees	Helios Aragon	Drilling permit obtained. Exploration from 2024
US	Arizona	Desert Mountain Energy	Exploration permit application
US	Kansas	Natural Hydrogen Energy	Test drilling completed in 2019
US	Nebraska	Hy Terra	Drilling completed. 2023 More production possible

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

Clean hydrogen trade is expected to emerge based on domestic supply and demand potential

- According to the International Renewable Energy Agency (IRENA), based on domestic supply and demand potential, the trade of clean hydrogen is expected to emerge.
  - Australia and Chile are cited as net exporters, and the US and Saudi Arabia also have high production potential.
- Several countries have approached countries that have this high clean hydrogen production potential, and it is important for Japan not to fall behind in securing suitable sites.

Clean hydrogen trade flow

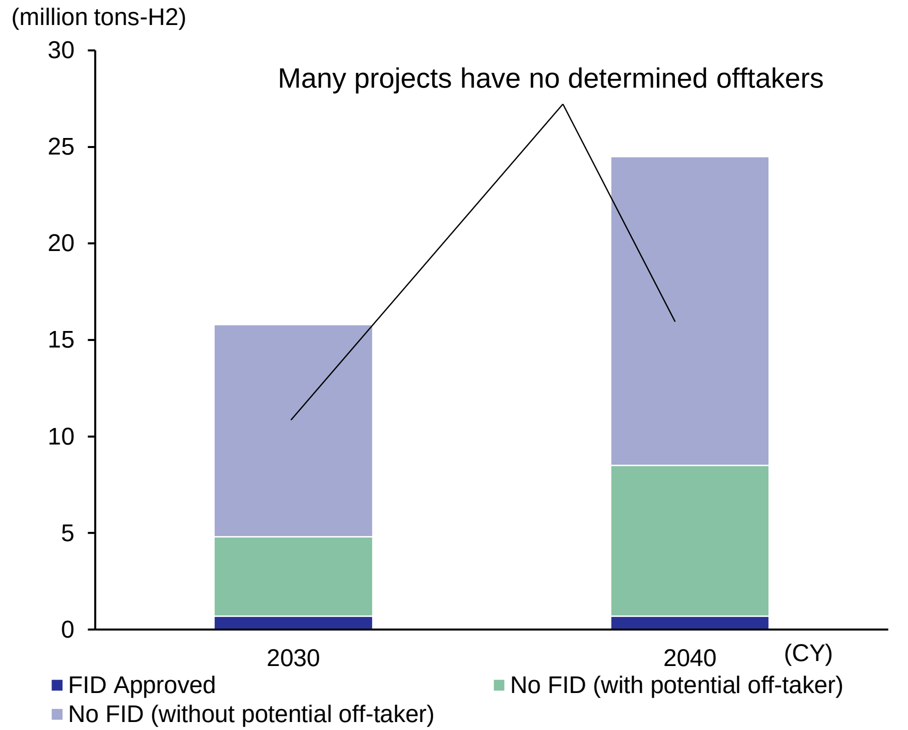


Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on IRENA, Global hydrogen trade to meet the 1.5°C climate goal

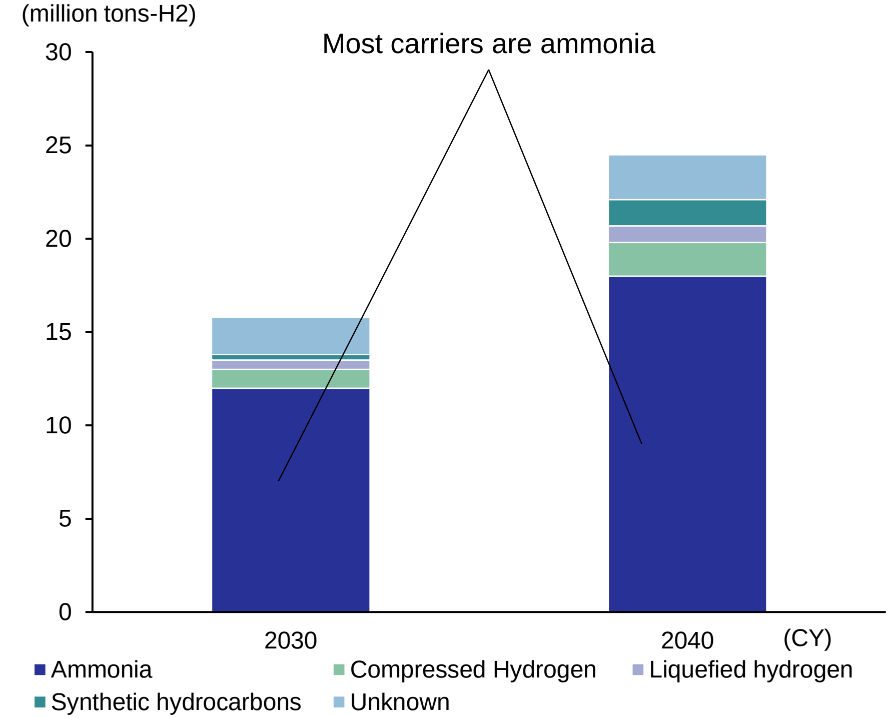
Many hydrogen export projects under consideration have yet to find offtakers

- Examining manufacturing projects based around exports, many projects are before FID and have no potential offtakers.
  - Various projects have been announced worldwide, but it's suggested that there are challenges in finding demand.
- The energy carrier (substance or method of transporting energy) used for export is mostly ammonia.
  - We believe this is because the supply chain already exists, export and import infrastructure is also in place, and handling is easier compared to other carriers.

Export outlook by status



Export outlook by carrier

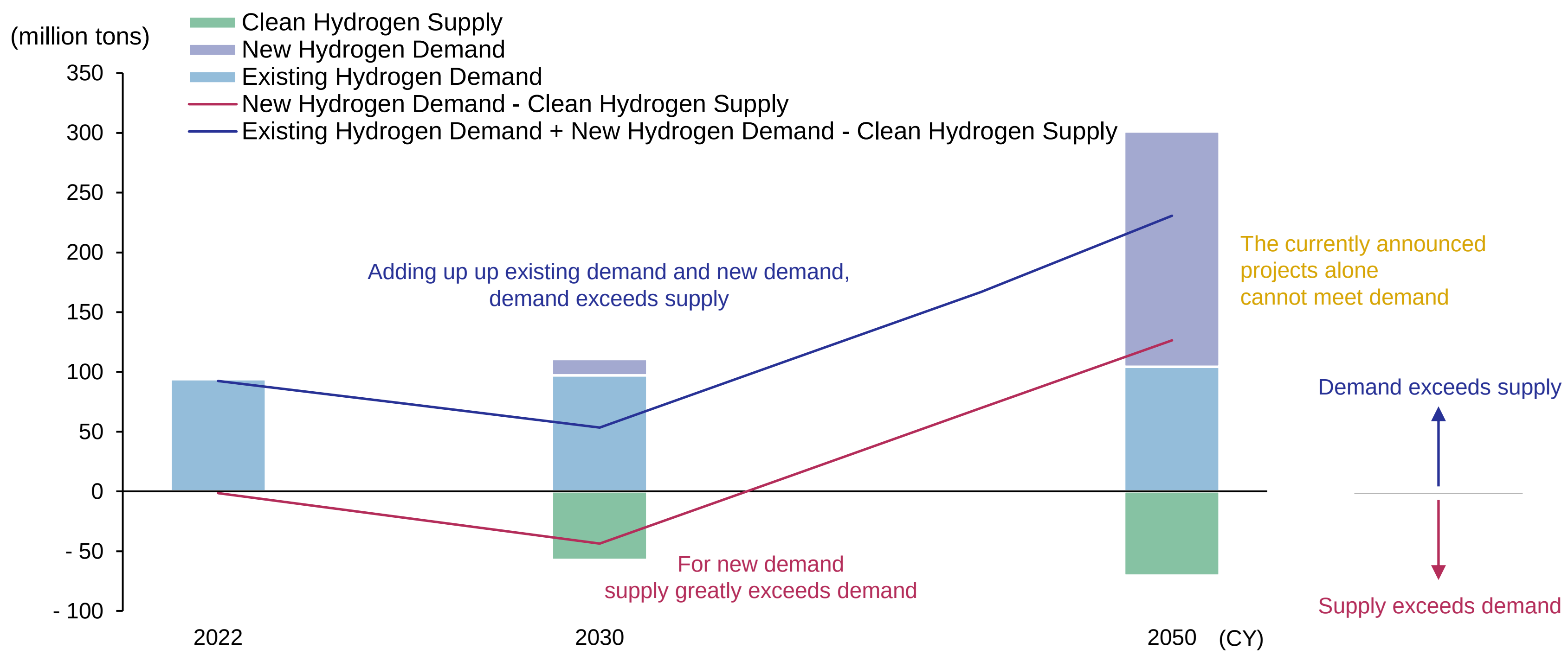


Source: Both charts compiled by Industry Research Department, Mizuho Bank, Ltd. based on IEA, Global Hydrogen Review 2023

Supply and demand balance outlook—In the future, there is a possibility of demand exceeding supply

- As of 2030, supply will exceed new demand, but if existing demand is included, demand exceeds supply.
- To match supply and demand in the short to medium term, in addition to developing new demand, promoting the conversion of existing demand to clean hydrogen is important.
  - If demand does not increase well, the number of projects that proceed to FID will be limited.
- By 2050, it is calculated that the current announced manufacturing projects alone will not meet demand.

Supply and demand balance outlook



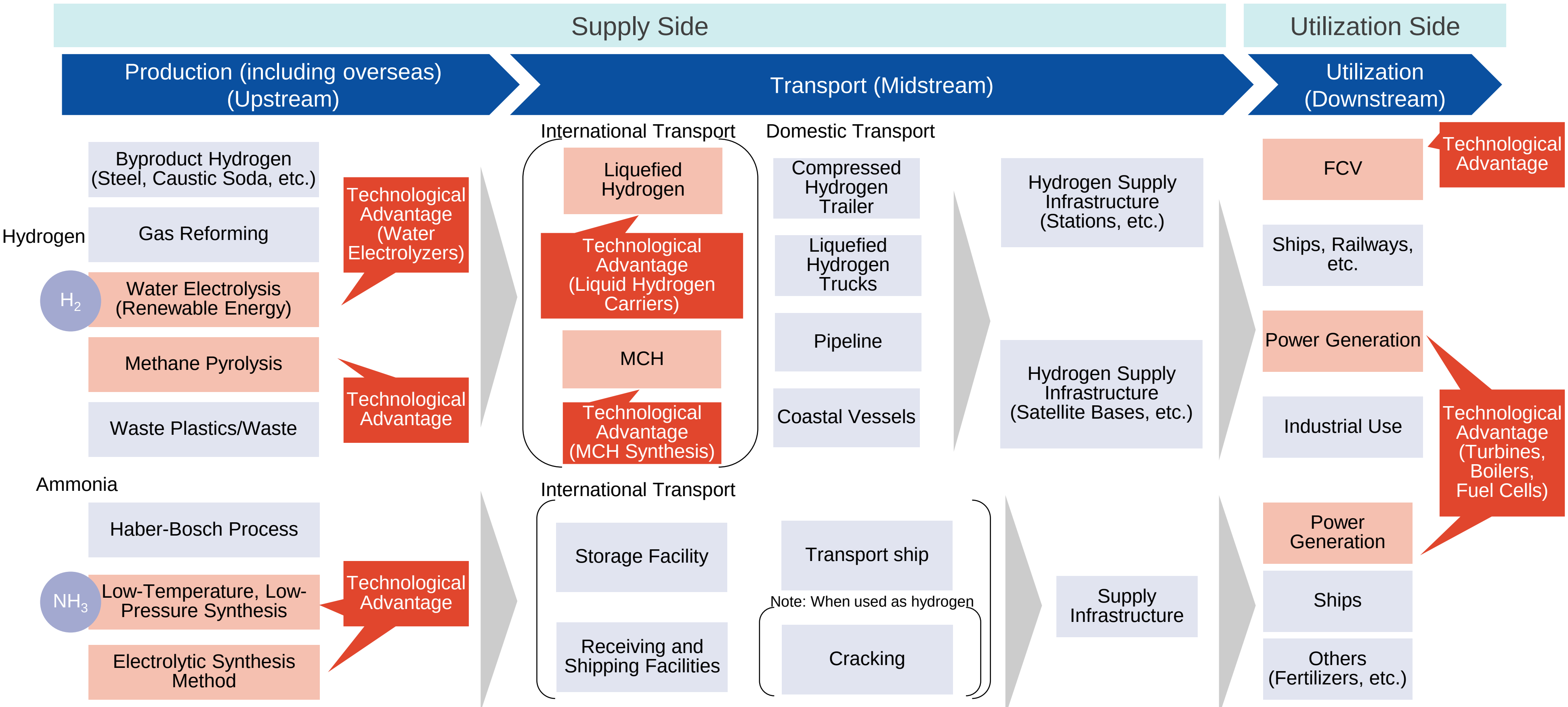
Source: Compiled by Industry Research Department, Mizuho Bank, Ltd.

4. Fields where Japan holds technological advantages

Japan has multiple upstream, midstream, and downstream technologies that can provide it with advantages in "earning with hydrogen"

- The hydrogen and ammonia supply chain is broadly divided into upstream, midstream, and downstream, and Japanese companies possess technologies that can efficiently produce, transport, and utilize hydrogen at each stage.
- Japanese companies' methods for marketing and turning these technologies into business opportunities is key to building a system where they can "earn with hydrogen.

The hydrogen supply chain and (certain) areas where Japan possesses technological advantages

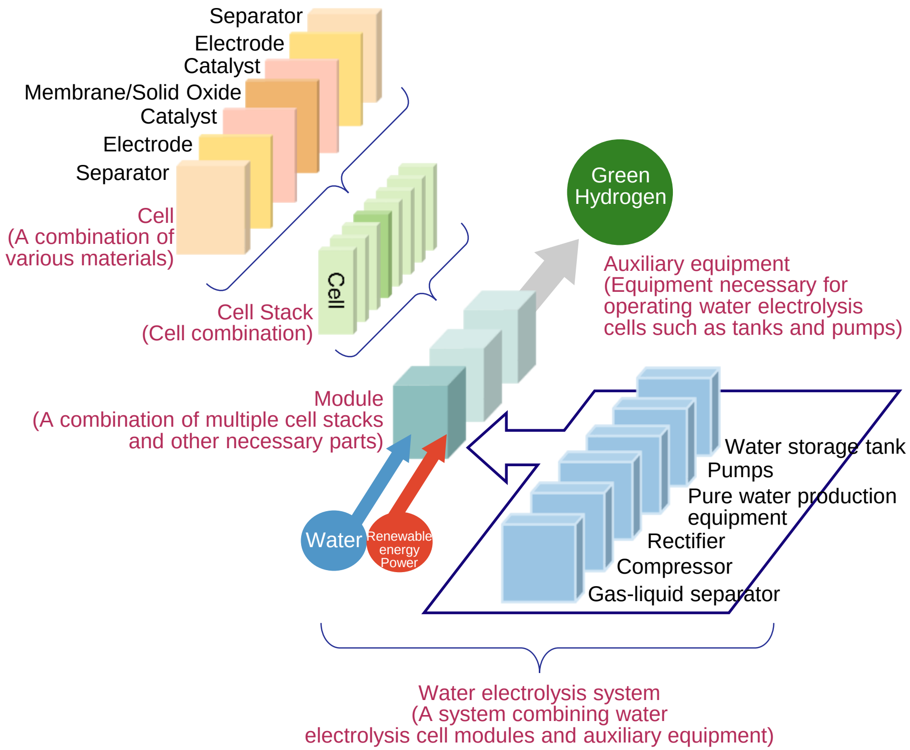


Note 1: Primarily listed technologies mentioned in the Basic Hydrogen Strategy
Note 2: MCH: Methylcyclohexane, a liquid made by adding hydrogen to toluene
Source: Compiled by Industry Research Department, Mizuho Bank, Ltd.

Manufacturing technology (1) water electrolyzers

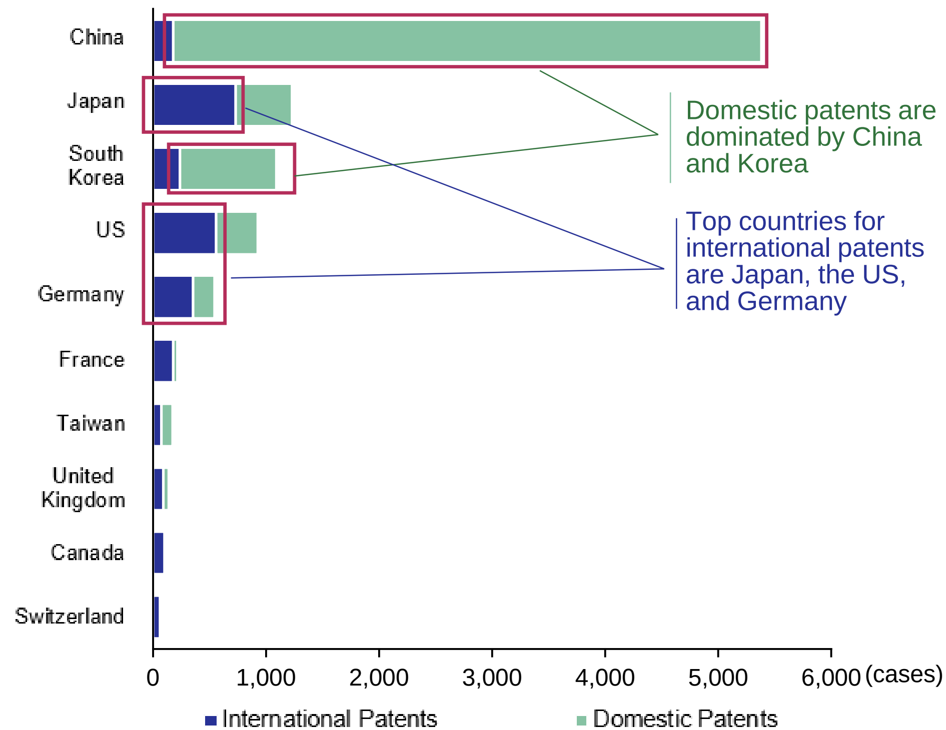
- Water electrolyzers are needed to produce hydrogen through electrolysis.
- While manufacturers in Japan, Europe, the US, and China are aiming to expand their presence, Japan holds many international patents and has strong technological capabilities.

Basic mechanisms of water electrolysis systems



Note: For details, refer to Mizuho Bank "Strategies for Japan to Demonstrate Presence in the Hydrogen Industry Using Innovative Technology Series: A Focus on Water Electrolysis Cells" in "Mizuho Short Industry Focus No.209" (July 25, 2023)
Source: Compiled by Industry Research Department, Mizuho Bank, Ltd.

Top countries by number of patents granted for water electrolyzers (2005-2020)



Note: Total number of patents granted from 2005 to 2020
Source: IRENA, Innovation trends in electrolysers for hydrogen production, and Compiled by Industry Research Department, Mizuho Bank, Ltd.

Manufacturing technology (2) methane pyrolysis

- Methane pyrolysis, where methane is decomposed into hydrogen and carbon by applying heat, is being researched as an innovative technology for hydrogen production.
- Methane pyrolysis is a method characterized by (1) not using water, (2) not emitting carbon dioxide and obtaining solid carbon, and (3) utilizing existing gas infrastructure.
  - Hydrogen produced by methane pyrolysis is called turquoise hydrogen and is classified as low-carbon hydrogen.
- Among various methods, Japanese companies are focusing on methane pyrolysis technology that uses catalysts to reduce energy consumption, aiming to gain an advantage in this field.

Overview of hydrogen production technology by methane pyrolysis and companies working on it

Method		Overview	Business Operators, etc.	
			Non-Japanese	Japanese Grey = investor, ( ) = investee, etc.
Plasma pyrolysis [First of a kind commercial]		• Thermal decomposition of methane using plasma • Fast start-up is possible • A challenge is that producing plasma requires a lot of energy	Monolith (U.S.) HiiROC (UK)	Mitsubishi Heavy Industries (Monolith)
Catalytic pyrolysis [Full prototype at scale]	Molten metal or molten salt	• Thermal decomposition of methane by filling the reactor with molten metal or salt • Requires technology for handling molten metals/salts at temperatures of 1,000℃ or above	C-Zero (U.S.) PARC (U.S.)	Mitsubishi Heavy Industries (C-Zero)
	Other	• Thermal decomposition of methane using catalysts loaded with Ni or Fe as the active metal or iron ore, etc. as a catalyst • Deactivation of catalysts due to deposition of solid carbon is a challenge	Hazer (Australia) Hycamite (Finland)	Ebara Corporation, Toda Kogyo, Ihara Industries, IHI, Mitsubishi Heavy Industries Chiyoda Corporation (Hazer), Chubu Electric Power, Sojitz (Hycamite)
Thermal pyrolysis [Early prototype]		• Reaction occurs without using plasma or a catalyst	BASF (Germany) Modern Hydrogen (U.S.) Ekona Power (Canada)	Miura Co., Ltd. (Modern Hydrogen) Mitsui & Co. (Ekona Power)

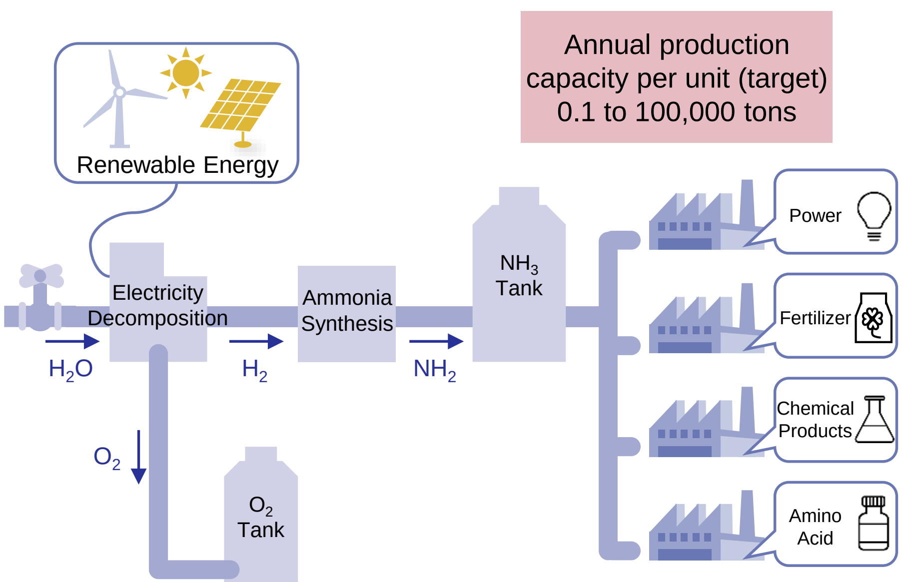
Source: Various published materials, Compiled by Industry Research Department, Mizuho Bank, Ltd.

Manufacturing technology (3) innovative ammonia production technology

- The Haber-Bosch method has become established as the process for ammonia production, but innovative production methods are being developed worldwide with an eye to expanding the use of clean ammonia, however, all of these require time to commercialize, and Japan can be said to have an advantage in this field.
  - Tsubame BHB, a venture from Tokyo Institute of Technology, has succeeded in miniaturizing production using a new catalyst
  - IHI is working on developing a direct electrolysis technology for ammonia.

Compact ammonia synthesis equipment (Tsubame BHB)

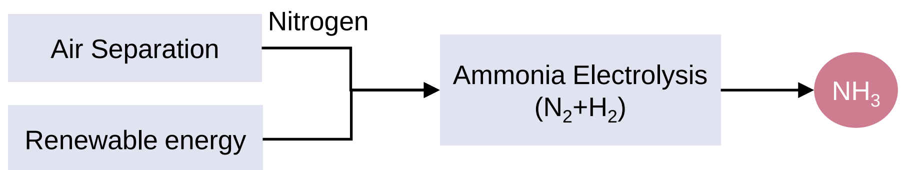
- Compared to the iron catalyst used in the Haber-Bosch process, ammonia synthesis using electride catalysts, which can synthesize ammonia at lower temperatures and pressures, and optimized plant design allow for on-site production.
- This contributes to reducing transportation and storage costs, as well as reducing environmental impact and costs.



Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on Tsubame BHB's website

Ammonia electrolysis

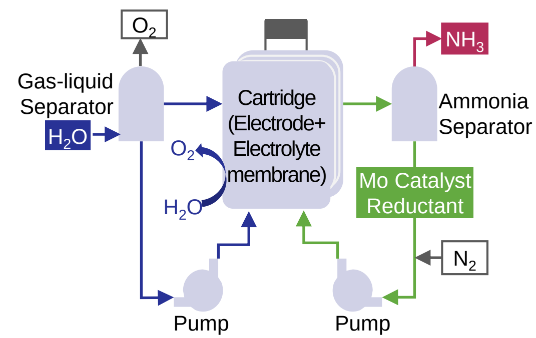
- IHI, Hokkaido University, Fukuoka University, The University of Tokyo, and De Nora Permelec are developing innovative technology to directly synthesize CO_2-free ammonia from water and nitrogen through NEDO projects.



Source: Prepared by Mizuho Bank's Industry Research Department based on IHI's website

Research and development of ammonia production technology at room temperature and pressure

- Idemitsu Kosan, through a NEDO project, is working with The University of Tokyo, Tokyo Institute of Technology, Osaka University, Kyushu University, AIST, Nissan Chemical, and Toshiba to establish new technology for ammonia production under mild reaction conditions at room temperature and pressure, and to develop mass production technology with high- cost competitiveness.



Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on Idemitsu Kosan's website

Transportation technology (1) liquefied hydrogen carriers

- Kawasaki Heavy Industries is developing and building liquefied hydrogen carriers in Japan, leading in this field globally.
  - — Although Korea Shipbuilding & Offshore Engineering (HD Hyundai G) is actively developing these carriers, has obtained basic design approval (2020) and has been involved in multiple demonstrations, it can be surmised that Kawasaki Heavy Industries' efforts are leading this field as it has succeeded in transportation and cargo handling with a demonstration ship.
- Since liquefied hydrogen is transported at -253℃, this type of ship requires advanced tank technology with a vacuum-insulated double-shell structure, making the barriers to entry high. Larger ships are important in reducing hydrogen costs, and the development and construction of large liquefied hydrogen carriers is an urgent task.

Hydrogen Project Deployment by Kawasaki Heavy Industries

2021

Pilot Demonstration

Hydrogen Cost 170 yen/Nm³

✓ A Japan-Australia pilot project was conducted through HySTRA completing the world's first demonstration of marine transportation and cargo handling of liquefied hydrogen using a carrier

[Marine Tank Size] 1,250m³

[Terminal Tank Size] 2,500m³

128 times

Around 2030

Commercial Demonstration

✓ Scaling equipment to commercial size to evaluate commercial viability, including economic aspects (GI fund project)

[Marine Tank Size] 160,000m³ (40,000m³ x 4)

[Terminal Tank Size] 50,000m³

2031 onwards

Commercial Chain

Hydrogen Cost About 30 yen/Nm³

✓ From facility installation to operation, envisioning an economically independent and profitable real business

[Marine Tank Size] 160,000m³ (40,000m³ x 4) X 2 ships

[Terminal Tank Size] 50,000m³ X 4 units

Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on Kawasaki Heavy Industries' published materials

Image of Hydrogen Costs

	Hydrogen Production + CCS	Hydrogen Liquefaction	Loading Base	Liquefied Hydrogen carriers	
Present	22 yen/Nm³ (0.1 t/day)	30 yen/Nm³ (5 t/day)	33 yen/Nm³ (2,500m³)	89 yen/Nm³ (36 t/day)	170 yen/ Nm³
2030 (Target)	14.7 yen/Nm³ (770 t/day)	9.4 yen/Nm³ (1,000 t/day)	3.2 yen/Nm³ (200,000 m³)	2.5 yen/Nm³ (225,000 t/day)	30 yen/ Nm³

For large-scale transportation of hydrogen and reducing hydrogen costs, the larger the liquefied hydrogen carriers, the better

Development Status of Competing Countries

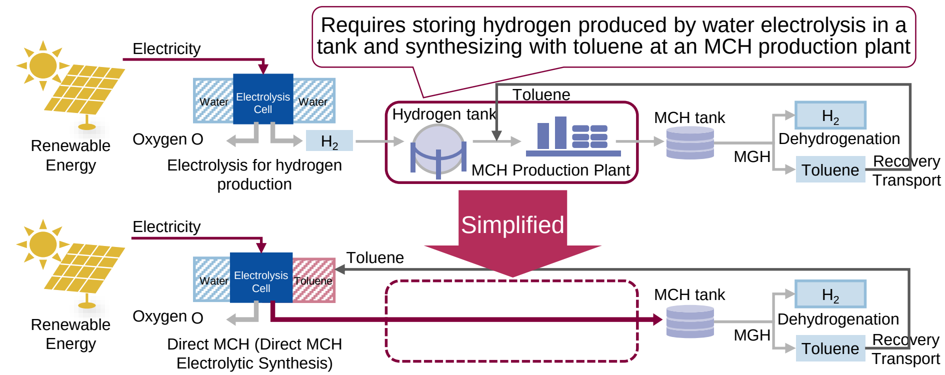
Shipbuilding Company	Tank Size	Commercialization Timeframe
Korea Shipbuilding & Offshore Engineering (HD Hyundai Heavy Industries)	20,000m³	2030
Samsung Heavy Industries	20,000m³	—
C-Job Naval Architects, LH2 Europe (Netherlands)	37,500m³	—
Samsung Heavy Industries	160,000m³	—

Source: Top chart from Kawasaki Heavy Industries materials, bottom chart from Ministry of Economy, Trade and Industry materials, compiled by Industry Research Department, Mizuho Bank, Ltd.

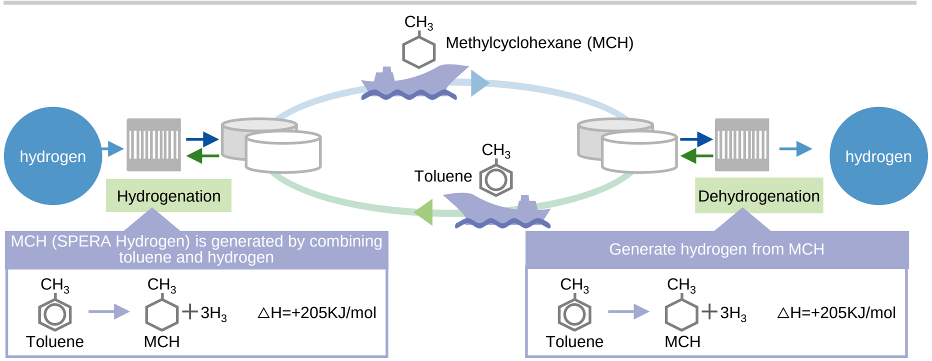
Transportation Technology (2) MCH

- ENEOS and Chiyoda Corporation have proprietary technologies for MCH.
  - ENEOS succeeded in the world's first verification of technology to directly synthesize MCH with an electrolytic cell—no need for hydrogen tanks or MCH production equipment.
  - Chiyoda Corporation has registered the trademark SPERA Hydrogen for MCH used for hydrogen storage and transportation and is deploying it globally.
- The cost of transporting and dehydrogenating MCH can be reduced by converting petroleum assets, so a full-scale social implementation is expected, particularly in regions with established petroleum marine export and import infrastructure.

ENEOS's Direct MCH Technology

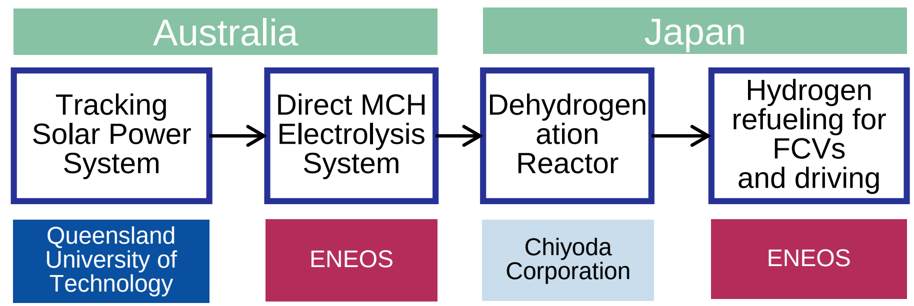


Chiyoda Corporation's SPERA Hydrogen



Source: Both charts compiled by Industry Research Department, Mizuho Bank, Ltd. based on publicly available information

Japan-Australia hydrogen supply chain demonstration by ENEOS and Chiyoda Corporation, etc.



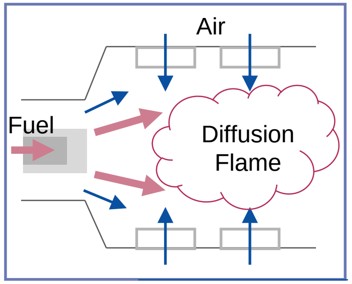
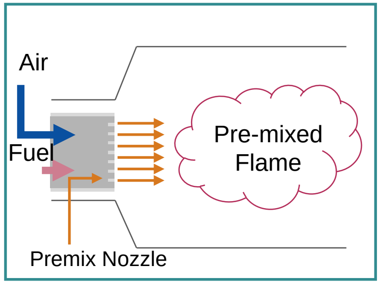
- ✓ Using ENEOS's Direct MCH technology, toluene is directly reduced to MCH without using hydrogen. This can reduce equipment costs related to MCH production by about 50%.
- ✓ Chiyoda Corporation's proprietary technology uses a dehydrogenation reactor and catalyst to enhance hydrogen yield through the dehydrogenation process.

Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on published materials.

Utilization technology (1) power generation – (i) hydrogen combustion technology

- There are two types of hydrogen combustion: diffusion combustion, where fuel and air are injected from separate nozzles, and pre-mixed combustion, where fuel and air are mixed in advance and then injected.
  - — Mitsubishi Heavy Industries succeeded in co-firing 30% hydrogen in a large gas turbine for the first time in the world, while Kawasaki Heavy Industries started selling a small gas turbine cogeneration system capable of hydrogen-exclusive firing using world-first technology.

Characteristics of each type of hydrogen gas turbine

Type	Diffusion Combustion	Pre-mixed Combustion
Type		
Methods for NOx Reduction and Traits	✓ Water Injection: Involves injection of water or steam —Since moisture absorbs part of the combustion energy, it is difficult to improve combustion efficiency	✓ Dry Method: A method of injecting pre-mixed fuel and air through many small nozzles, burning the fuel with small flames to eliminate localized high-temperature areas and keep NOx emissions consistently low — Controlling combustion temperature is difficult
Combustion Characteristics	✓ Fuel and combustion air are injected separately ✓ High-temperature spots are likely to occur ✓ Flame position is stable	✓ Fuel is mixed with air and injected ✓ High-temperature spots are less likely to occur ✓ Flame is unstable. Concerns about combustion oscillations and flashback (backfire)
Traits	✓ Wide tolerance for fuel property variations ✓ Simple fuel system	✓ Achieves both CO_2 reduction and low NOx emissions ✓ Complex fuel system

Note: NOx = Nitrogen Oxide
Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on a variety of publicly available information

Mitsubishi Heavy Industries: Succeeded in co-firing 30% hydrogen in a large gas turbine

- ✓ In November 2023, Mitsubishi Heavy Industries announced that it had successfully conducted a demonstration operation using JAC gas turbines (inlet temperature: 1,650℃) with a rated output of 566,000 kW at the GTCC demonstration power generation facility in Takasago Works. The fuel used was a mixture of city gas and 30% hydrogen by volume, in both partial load and 100% load conditions
- ✓ The demonstration used dry low NOx burners, and the hydrogen was produced within Takasago Works
- ✓ This was the world's first demonstration operation of a large gas turbine with 30% hydrogen-mixed fuel, using hydrogen produced and stored on the same site, connected to the local power grid

Source: Prepared by Mizuho Bank's Industry Research Department based on materials published by Mitsubishi Heavy Industries

Kawasaki Heavy Industries: Started selling a small hydrogen-exclusive firing gas turbine cogeneration system

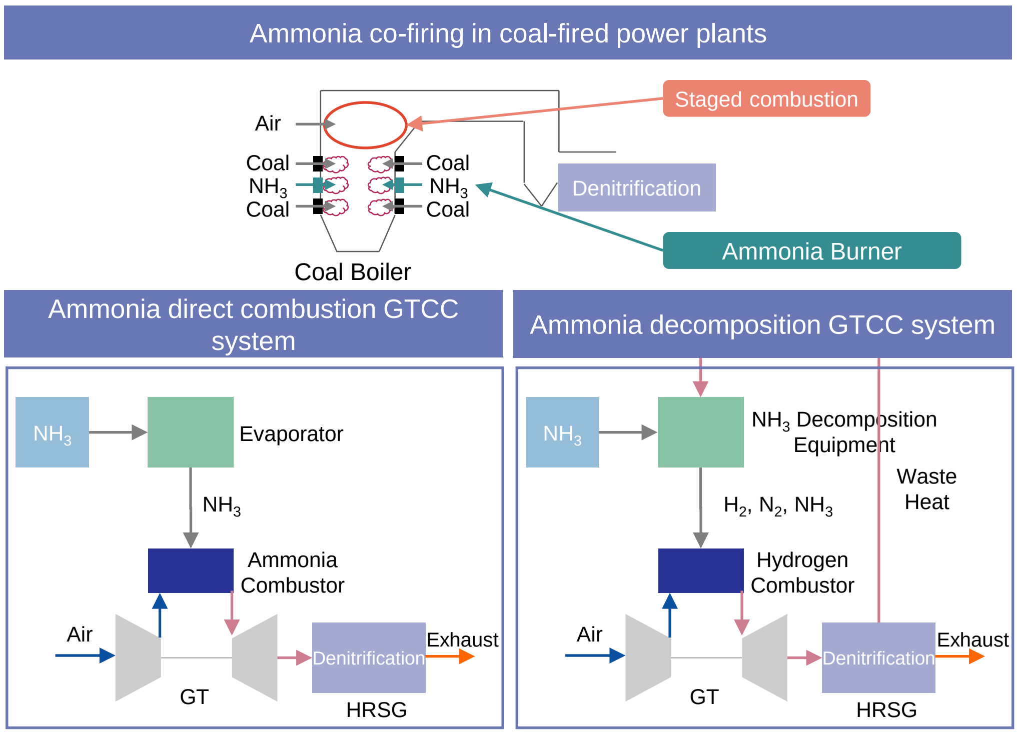
- ✓ In September 2023, Kawasaki Heavy Industries announced the start of sales of a 1.8MW-class gas turbine cogeneration system with a dry-type combustor capable of hydrogen-exclusive firing.
- ✓ This combustor utilizes micro-mix combustion (micro hydrogen flames), a technology developed by Kawasaki Heavy Industries as part of a NEDO technology demonstration, which successfully developed the world's first dry low NOx hydrogen-exclusive firing gas turbine technology
- ✓ The system supports hydrogen-exclusive firing combustion as well as co-firing with natural gas, allowing flexible operation according to the volume of hydrogen supplied, utilizing hydrogen from 50% to 100% by volume

Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on Kawasaki Heavy Industries' published materials

Utilization technology (1) power generation – (ii) ammonia combustion technology

- Ammonia combustion technology consists of two types: co-firing/ammonia-only firing in coal-fired power plants and ammonia gas turbines; Japanese companies such as IHI and Mitsubishi Heavy Industries are leading the development of this technology.
  - IHI, in collaboration with JERA, started a demonstration of ammonia co-firing in a coal-fired power plant at Hekinan Power Station Unit 4 in April 2024, the first such large-scale commercial boiler demonstration in the world; additionally, IHI plans to collaborate with GE Vernova to develop combustors for ammonia-exclusive gas turbines.
  - In November 2023, Mitsubishi Heavy Industries succeeded in an ammonia-exclusive combustion test in a combustion test furnace and is developing small to medium-sized ammonia-exclusive gas turbines that has yet to be realized in the world.

Ammonia combustion-related technologies



Note: GT: Gas Turbine, GTCC: Gas Turbine Combined Cycle, HRSG: Heat Recovery Steam Generator
Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on a variety of publicly available information

IHI: Ammonia combustion initiatives

Ammonia co-firing/ exclusive firing in coal-fired power plants	✓ As part of the GI fund project, IHI, in collaboration with JERA, is developing and demonstrating high-ammonia co-firing technology in coal boilers. From April 2024, a large-scale demonstration of 20% ammonia co-firing in fuel started at Hekinan Power Station Unit 4 (the world's first in a large commercial furnace)
Ammonia-exclusive gas turbine development	✓ IHI and GE Vernova signed a memorandum of understanding for the development of ammonia-exclusive gas turbines, collaborating on developing combustors that use ammonia as fuel for GE Vernova's 6F.03, 7F, and 9F gas turbines

Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on materials published by IHI

Mitsubishi Heavy Industries: Initiatives related to ammonia combustion

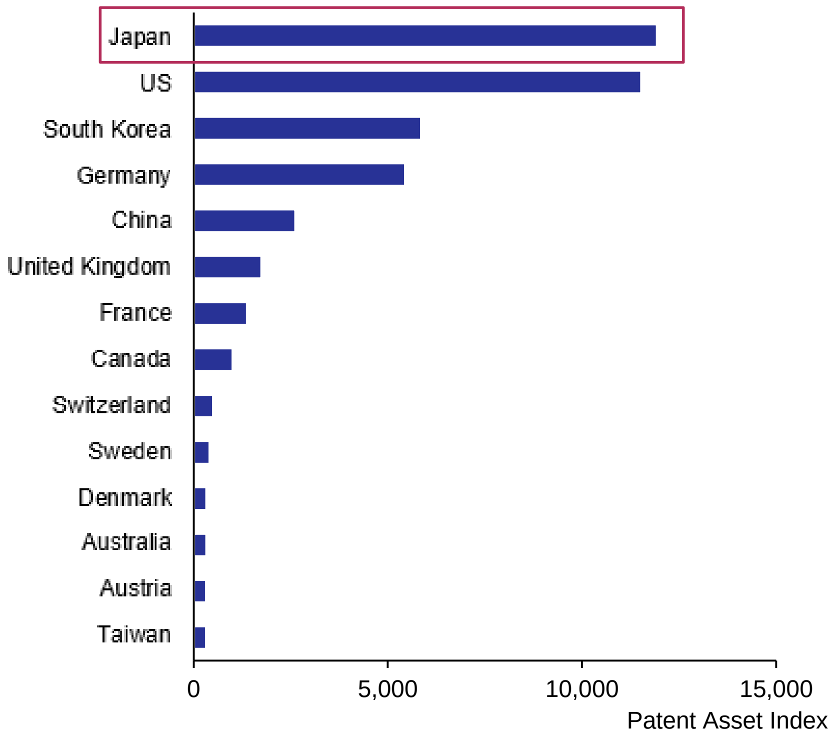
Ammonia co-firing/ exclusive firing in coal-fired power plants	✓ In November 2023, Mitsubishi Heavy Industries announced the successful completion of tests for ammonia-exclusive firing and high co-firing with coal using an ammonia-only burner in a combustion test furnace with a fuel consumption rate of 0.5 tons/hour
Ammonia-exclusive gas turbine Development	✓ Since 2021, Mitsubishi Heavy Industries has been developing the world's first 100% ammonia direct combustion gas turbine system using the H-25 gas turbine (output: 41.0MW). Development of an ammonia decomposition GTCC system is also planned

Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on materials published by Mitsubishi Heavy Industries

Utilization technology (2) fuel cells

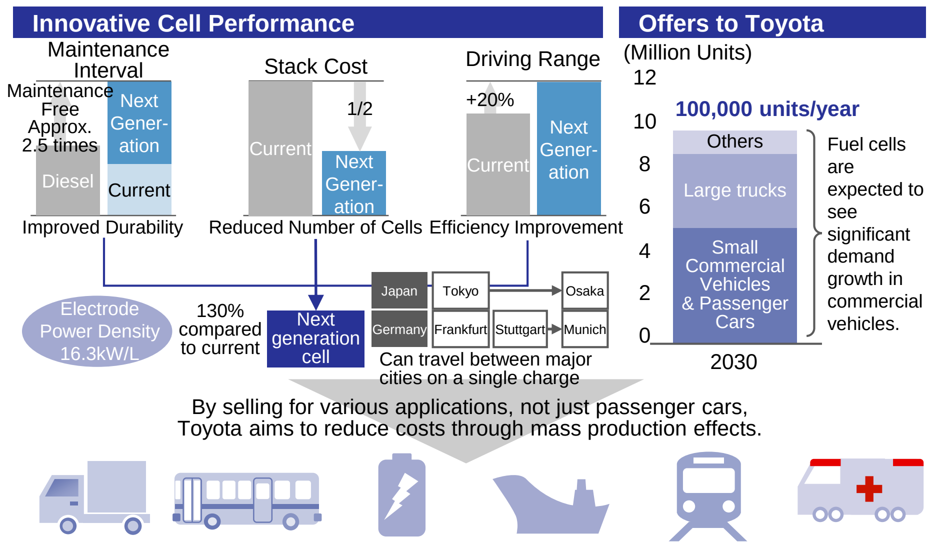
- In the fuel cell field, Japan holds many highly competitive patents and has a technological advantage.
- Toyota, as an FCV manufacturer, has successfully reduced the size of fuel cell systems, achieving world-class power density. Furthermore, Toyota is developing an innovative next-generation fuel cell system and is focusing on external sales in collaboration with various partners for trucks, buses, ships, railways, special vehicles, and stationary applications.

Competitiveness comparison of fuel cell-related patents based on the Patent Index



Note: Patent Asset Index: An indicator representing the total asset value of all patents held, calculated by summing the relative value of patents based on citation frequency and market size across the entire portfolio.
Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on PatentSight

Toyota's fuel cell expansion strategy



Trucks	Buses	Stationary Fuel Cells	Ships	Railways	Heavy Machinery/ Special Vehicle
Fuel cell trucks are gaining attention as a way of achieving a sustainable society that addresses global warming and energy diversification.	Already progressing towards practical use, models with higher safety, transportation capacity, and improved speed and punctuality are under development.	Demonstration experiments of stationary fuel cells are advancing for carbon neutral efforts in factories and for microgrids.	Worldwide and in Japan, the development and demonstration of ships using hydrogen as fuel is progressing.	The development of railway vehicles using hydrogen as an energy source contributes to the realization of a decarbonized society by preventing global warming and energy diversification.	The installation of fuel cells in heavy machinery and special vehicles is progressing to help realize a hydrogen society.

Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on publicly available information

5. Conclusion

Globally, the process of social implementation and business opportunities will vary by region

- Supply-demand conditions and primary uses will differ according to the energy potential and economic structure of each country and region.
- Creating business opportunities tailored to the local situation that are aligned with the process of social implementation will be most effective.

Implementation Process of a Global Hydrogen Society

Europe

Short to Mid-term

[Demand]
- Replacement of existing uses such as oil refining and chemicals will lead, with gradual growth in steel and SAF manufacturing.
- In power sector, the capacity of renewable energy will increase. Retrofit will advance for hydrogen co-firing in thermal power plants (hydrogen ready), but actual use will be limited.

[Supply]
- Mainly domestic production, with some imports from neighboring countries (Middle East, North Africa, South America).

Long-term

[Demand]
- Increased use in mobility (automobiles, shipping, aviation).

[Supply]
- Import ratio will increase in line with expanding domestic demand.

Assumed Business Opportunities:
Supply of water electrolysis units
(for domestic production)
Supply of liquefied hydrogen carriers
(for imports from neighboring countries).

US

Short to Mid-term

[Demand]
- Expansion of utilization in existing uses such as oil refining and ammonia production centered on hydrogen hubs.

[Supply]
- Focus on domestic production and exports leveraging IRA.

Long-term

[Demand]
- Increased use in mobility (automobiles, SAF) and power generation.

[Supply]
- Expansion of production to match global demand growth.
- Promote exports to maintain position as an energy supply country.

Note: Decarbonization policies may change depending on the administration

Assumed Business Opportunities:
Supply of water electrolysis units
(for domestic production)
Supply of fuel cells
(for data centers and forklifts)
Provision of MCH production technology anticipating the repurposing of petroleum assets.

Business Opportunities:
Support for building trading and import supply chains

China

Short to Mid-term

[Demand]
- Industrial use will lead.

[Supply]
- Mainly domestic production.

Long-term

[Demand]
- Increased power generation demand due to the need to maintain thermal power generation.
- Increased use in steel and mobility is also expected.

[Supply]
- Coexistence of supply from hydrogen production sites to nearby areas and imports from overseas to major demand areas across vast areas.

Assumed Business Opportunities:
Export of hydrogen and ammonia power generation technology
Provision of turquoise hydrogen production technology (using LNG infrastructure)
Supply of FCVs
Supply of liquefied hydrogen carriers
(capable of providing high-purity hydrogen)

Japan

Short to Mid-term

[Demand]
- Large-scale demand for power generation will lead, gradually creating nearby uses in steel and chemicals

[Supply]
- Limited domestic production potential, with most being imported
- Development of receiving and supply bases centered on power plants and industrial complexes

Long-term

[Demand]
- Power generation and gas energy substitution will be the main demand
- Domestic industrial locations may be reorganized around hydrogen receiving and supply bases which are favorable for CN compliance

[Supply]
- Although domestic production will gradually increase, most will be imported

Source: Compiled by Industry Research Department, Mizuho Bank, Ltd.

Japan's global aspirations - promoting Japanese technology and expanding hydrogen handling

- Rather than lumping the global market together, aiming to promote Japanese technology and expand hydrogen handling through considering regional characteristics, will help strengthen its global presence in the hydrogen sector.
- However, there are gaps such as delays in the commercialization of hydrogen-related equipment manufacturers, and Japanese technologies like ammonia co-firing are not well understood or recognized globally, so strategies are required to overcome these challenges.

Global ideal and challenges

Desired State	Examples	Gaps with Current State (Challenges)
1 **Promote Japanese Technologies Considering Regional Characteristics**	■ Expand installation capacity of Japanese-made water electrolysis units in hydrogen-producing countries ■ Promote turquoise hydrogen production in LNG importing countries (e.g., China) ■ Utilize liquefied hydrogen, suitable for medium-distance transport, not only for imports to Japan but also for routes like North Africa to Europe and Southeast Asia to China ■ Expand hydrogen and ammonia power generation as a bridgehead in Asia and the global south, and spread it globally ■ Expand sales of fuel cells to environmentally conscious consumers, as power backups for data centers, etc., (which are expected to grow with the spread of generative AI and connected cars)	■ Japanese manufacturers are slower in commercialization compared to foreign companies Example: Water Electrolysis Units, etc. Measures: P38 Left Diagram ■ Japanese technologies with advantages in this area have not yet established a global standard position Example: MCH, Liquefied Hydrogen, Ammonia Co-firing Power Generation, etc. Measures: P38 Right Diagram
2 **Expand Japanese Companies' Hydrogen Hand**	■ Strengthen support for building trading businesses and import supply chains targeting major demand areas outside Japan ■ Expand overseas interests	■ Many companies enter the hydrogen business with a focus on supplying Japan, not the global market ■ Insufficient investment amounts Measures: P39

Source: Compiled by Industry Research Department, Mizuho Bank, Ltd.

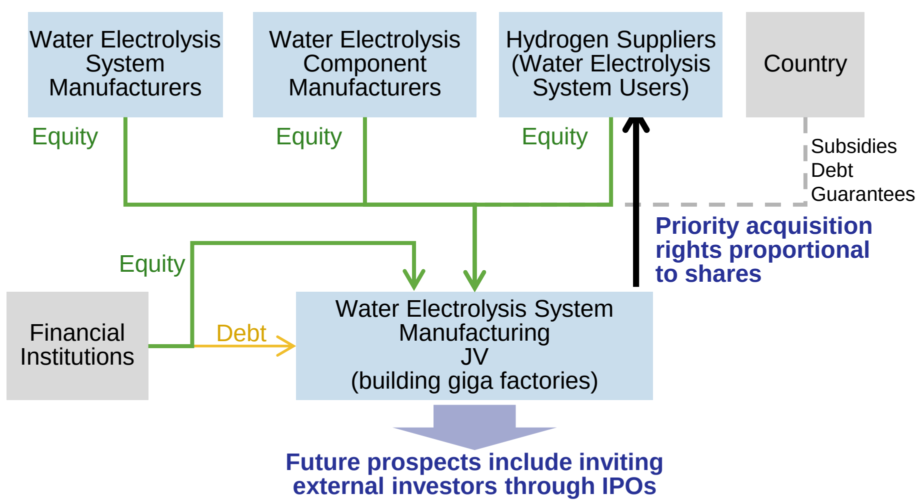
Accelerated decision-making and increased awareness are effective for promoting technology

- The difficulty in commercializing hydrogen-related products is partly due to the uncertain demand in Japan, the mother market, and the difficulty in raising investment funds—promoting schemes that cleverly leverage external funds and expedite decision-making through public-private partnerships is a key measure.
- To globally promote Japan's advantageous technologies, collaboration with countries and regions with similar geographical characteristics and the dissemination of accurate information worldwide through owned media are effective strategies.

Measures to promote the commercialization of manufacturers using water electrolysis units as an example

Commercialization utilizing external funds Public Private

Examples



- ✓ Manufacturers with excellent technologies can spin off businesses, pooling investment funds across multiple companies to reduce risk and expedite decision-making
- ✓ Joint participation by manufacturers and users enables stable long-term transactions for both parties

Source: Compiled by Industry Research Department, Mizuho Bank, Ltd.

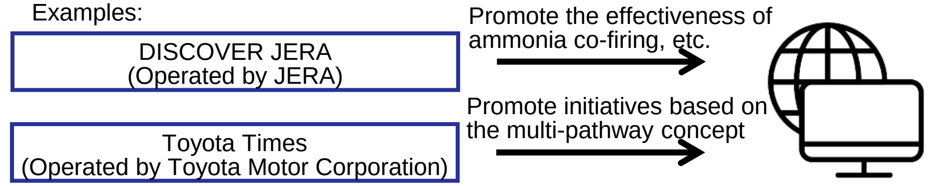
Measures to increase awareness and understanding of Japan's advantageous technologies

Collaboration with countries and regions with similar geographical characteristics to Japan Public Private

- ✓ Countries like South Korea, Southeast Asia, and India, which have difficulties achieving energy self-sufficiency, have similar geographical characteristics to Japan and are strong candidates for creating partnerships
- ✓ Japan, which is leading in building hydrogen import and utilization supply chains, can collaborate with local companies to create hydrogen demand while increasing awareness of its technologies

Information dissemination through owned media Private

Examples:



- ✓ Companies with technologies they want to raise awareness of can communicate their strategies and philosophies
- ✓ Provide in-depth explanations of the background information of individual measures that are limited by press releases and mass media

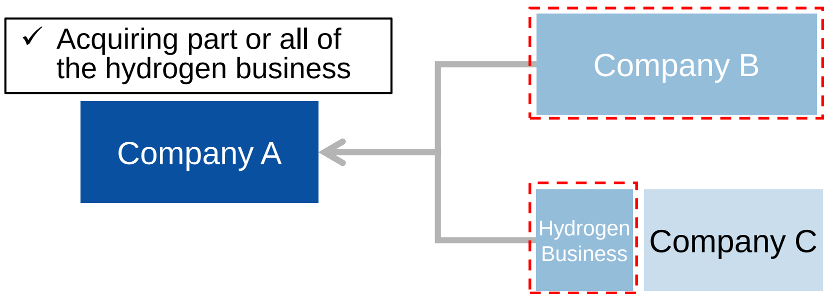
Source: Compiled by Industry Research Department, Mizuho Bank, Ltd.

In the mid to long term, it is expected that hydrogen portfolio players that transcend the Japanese market will be created

- In hydrogen business, besides selling a wide range of technologies, it is hoped that Japanese-origin portfolio players will be created to profit in upstream areas. Core companies must strengthen their sales and procurement capabilities by promoting business integration.
  — Additionally, Japan becoming a hub for hydrogen transactions is anticipated to stimulate hydrogen trading.
- It is presumed that Japan, which is expected to demand hydrogen on a large scale, will find it easier to deepen relationships with both exporting and importing countries from the early stages.
  — We believe it is essential to actively explore securing upstream interests leveraged by offtake agreements.

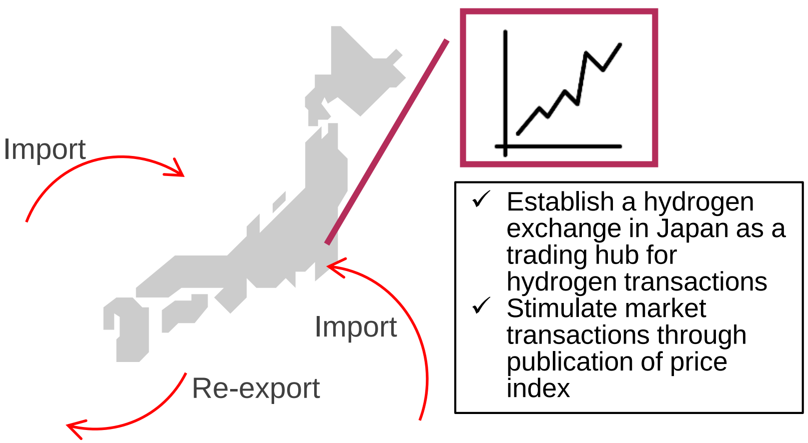
Business integration for the creation of hydrogen portfolio players

Private



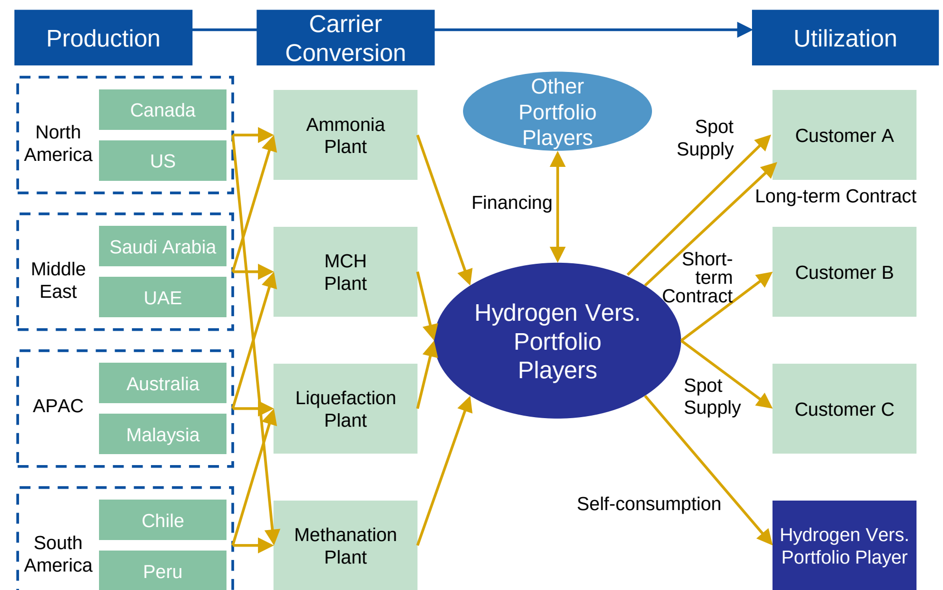
Establishing a hydrogen trading hub in Japan to stimulate trading

Public Private



Source: Both charts compiled by Industry Research Department, Mizuho Bank, Ltd.

Image of roles of hydrogen portfolio players



✓ Deepen relationships with exporting and importing countries from the early stages of the market, and play a leading role in the expansion of the hydrogen market while securing multiple interests, multiple demand destinations, and infrastructure like tanks and fleets, thereby creating hydrogen portfolio players originating in Japan
✓ If there is a certain level of self-demand, it can be leveraged to participate in interests and secure procurement volumes

Source: Compiled by Industry Research Department, Mizuho Bank, Ltd.

Japan's domestic aspirations - early market expansion and improved supply stability

- It is crucial to expand the hydrogen utilization market in Japan at an early stage, enhance Japan's global influence on the supply chain, and strengthen energy security and resilience beyond fossil fuels.
- Challenges exist in achieving this desired state, and as on the global stage, strategies to overcome these are required.

Japan's ideal vision and challenges

Desired State	Examples	Gaps with Current State (Challenges)
1 **Expand the mother market early and strengthen influence as a major demand country**	■ Achieve hydrogen demand targets for 2030, 2040, and 2050 ■ Broaden the scope of hydrogen use for commercial and residential purposes, expanding demand beyond government targets	■ It is somewhat unclear whether the first movers who are pioneering the construction of the hydrogen supply chain will be able to establish a supply chain at an early stage (Measures: P41 Left Diagram) ■ Unclear support for post-2030 first movers ■ Insufficient progress in greenification of existing gray hydrogen (Measures: P41 Right Diagram)
2 **Leveraging the diverse supply sources and domestic production potential of hydrogen to enhance energy security and resilience beyond fossil fuels**	■ Maximize domestic hydrogen production ■ Improve the self-development ratio and diversify import sources to reduce geopolitical risks	■ Domestic hydrogen production is low (Measures: P42)

Source: Compiled by Industry Research Department, Mizuho Bank, Ltd.

It will be effective to accelerate supply chain construction by land acquisition and supporting the creation of second movers

- Domestically, it is necessary to accelerate supply chain construction through land acquisition and support the creation of second movers to ensure market expansion beyond 2030.

Importance of land acquisition during the transition period (Public)

Post-war reconstruction period

- ✓ Japan's industrial production facilities were heavily damaged after World War II
- ✓ Post-war, government-owned land, such as military facilities, was sold to private companies
- ✓ In other words, businesses could easily secure large plots of land during post-war reconstruction and introduce state-of-the-art equipment without land constraints

Very different circumstances

Present to future transition period

- ✓ Companies need to invest in equipment for energy transition while maintaining the CO_2-intensive equipment they have used for decades
- ✓ Companies will need to own both "gray equipment" and "transition equipment" simultaneously, but securing vacant land is particularly difficult in industrial complexes

✓ Currently, the establishment of hydrogen receiving and supply bases is being considered mainly by local companies. However, to secure land in industrial clusters, the government needs to be involved in removing barriers by preparing new reclaimed land and promoting the introduction of transition equipment.

Source: Compiled by Industry Research Department, Mizuho Bank, Ltd.

Creation of second movers for market expansion beyond 2030 (Public) (Private)

Immediate government support

- Support focused on price differences
- Support for base development

+

Support targets ("First movers")

- Projects to start supply by 2030
- Business innovation in hard-to-abate sectors like steel and chemicals
- Projects recognized as strengthening international competitiveness of industries
- Support for price differences is for the projects over 1,000 tons/year production, and support forbase development is for projects over 10,000 tons/year

Creation of second movers is yet to begin

- ✓ It is, therefore, necessary to promote the supply and use of clean energy in tandem, based on the S+3E principle
- ✓ The government needs to not only control prices, including raising CP, but also to take detailed and careful action to understand and resolve the specific challenges faced by different demand sectors with various bottlenecks. For example, maritime shipping has yet to determine its main CN fuel, the steel industry needs rule-making for green steel environmental value certification, and the power generation sector faces uncertainty about the viability of ammonia co-firing.
- ✓ Promoting the greenification of existing gray hydrogen is also expected
- ✓ Businesses need to develop services to improve the convenience of hydrogen use. For example, refining Energy as a Service to enable seamless fixed-rate use for the introduction, supply, and maintenance of hydrogen utilization equipment
- ✓ Increasing liquidity through the establishment of a hydrogen exchange is expected to reduce entry barriers

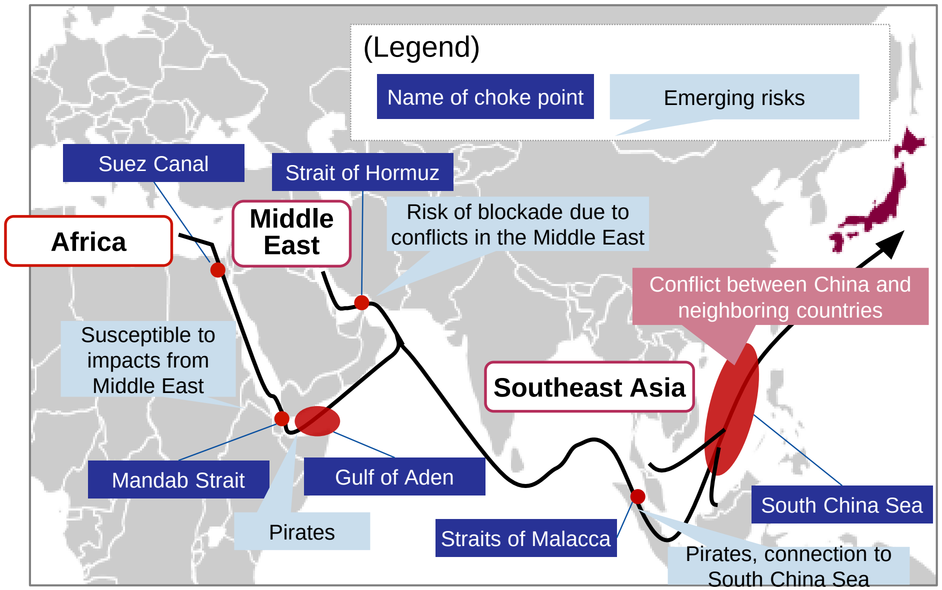
Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on materials from the Hydrogen and Ammonia Policy Subcommittee

Diversifying hydrogen procurement sources is needed for energy security

- For energy security, it is essential to diversify procurement sources and maximize the use of domestic hydrogen.
- Maximizing the production of green, pink (yellow) hydrogen using renewable and nuclear power, and turquoise hydrogen using LNG infrastructure will be effective for this.

Representative choke points and the importance of diversified procurement for Japan

Public Private



To ensure energy security, it is essential to diversify import sources and maximize the use of domestic hydrogen

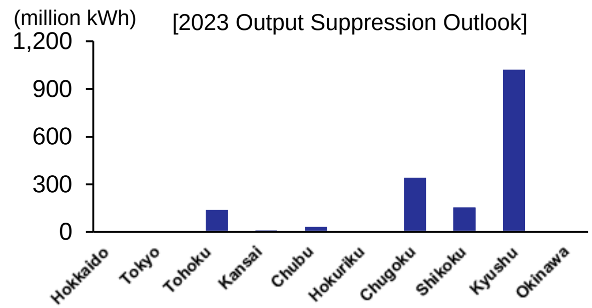
Maximizing the production of hydrogen using renewable power (green hydrogen), hydrogen using nuclear power (pink/yellow hydrogen), and hydrogen from methane pyrolysis (turquoise hydrogen) is effective for improving this

Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on various public materials

Maximize domestic hydrogen production

Public Private

Promote hydrogen production and local consumption using surplus renewable energy



- ✓ Focus on promoting hydrogen production in areas with high output suppression like Kyushu, Chugoku, and Shikoku
- ✓ However, the decline in electrolyzer operation rates due to fluctuating power sources is a bottleneck

Utilize nuclear power to promote hydrogen production

- ✓ Nuclear power is suitable for low-cost hydrogen production due to its low and stable power generation costs
- ✓ Pursuing the maximum operation of nuclear power will contribute to decarbonizing power sources and expanding domestic hydrogen production

Promote turquoise hydrogen production

- ✓ Japan currently imports around 70 million tons of LNG from various countries and possesses LNG import infrastructure Promoting turquoise hydrogen is suitable for transitioning while utilizing existing infrastructure and diversifying procurement
- ✓ Turquoise hydrogen must be positioned as an important energy source for Japan, and the development of manufacturing technology and the effective use of by-product carbon by Japanese companies must be promoted

Source: Compiled by Industry Research Department, Mizuho Bank, Ltd. based on materials from the System WG of the Agency for Natural Resources and Energy

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