How Japan Can Win the Global Competition for Hydrogen:

Mizuho's vision for a hydrogen supply and demand structure

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Summary

- Japan formulated the world's first national hydrogen strategy, the "Basic Hydrogen Strategy," in 2017. Since then, it has been a frontrunner in the global hydrogen industry. However, the EU is also gaining a presence, with plans to create 20 million tons of hydrogen demand by 2030 through upstream interests and REPowerEU. This report uses analyses of Japan's hydrogen supply and demand outlook and costs to consider how our resource-poor nation can stably procure hydrogen and what strategies are needed to succeed internationally in the hydrogen sector.
- According to our estimates, domestic hydrogen demand in Japan will be around 1.5 million tons in 2030 and about 24 million tons in 2050. By 2050, domestic hydrogen demand will be centered around power generation (9 million tons), gas energy substitution (8 million tons), and automobiles (3.5 million tons), with demand growing rapidly as 2050 approaches.
- Japan can potentially supply 4 to 5 million tons/year of domestic hydrogen by 2050, meaning an additional 20 million tons from overseas sources will be required. Multiple hydrogen production projects are being launched abroad, with imports from the Middle East, Australia, and North America expected to be the main sources, targeting exports to Asian markets. In terms of supply cost estimates, Middle Eastern blue ammonia/hydrogen will be the most cost-competitive by 2050, followed by U.S. blue ammonia and Australian blue hydrogen.
- To win the competition for hydrogen against these foreign competitors, Japan must ensure steady hydrogen use and stable procurement. It is important for Japan to provide policy support that benefits both exporting and importing countries, such as: (1) Establishing balanced support systems; (2) Creating local hydrogen hotspots using a concentrated approach to quickly boost hydrogen demand; (3) Securing early commitments from hydrogen suppliers through joint procurement frameworks and providing cutting-edge technology.
- However, it is also crucial for Japan to promote domestic production of CO2-free hydrogen to improve energy self-sufficiency and reduce hydrogen supply costs. While Japan's green hydrogen supply potential is limited due to scarce renewable energy resources, other options such as blue hydrogen from fossil resources or yellow hydrogen from nuclear power could be viable.
- By uniting the government and related businesses to establish early hydrogen demand and secure both domestic and international hydrogen supply sources, Japan can succeed against international competition in the hydrogen sector.

Source: Compiled by the Industry Research Division of Mizuho Bank.

Why focus on hydrogen?

- As an energy medium, Hydrogen is clean, emitting no CO_2 during utilization. It can be used to achieve carbon-free energy through the use of renewable energy (RE) and Carbon Capture and Storage (CCS) and allows for the storage and long-distance transportation of large amounts of electricity.
- It is expected to be a viable solution for various energy challenges, serving as a power source for transportation modes (mobility) and industrial demand, and is gaining global attention as a key energy source for achieving carbon neutrality.

Traits of Hydrogen and its Expected Role

Hydrogen's Traits

Hydrogen (H_2)

- Can be used as a clean, high-energy-efficiency energy source that does not emit CO_2 during combustion
- Can be produced from various resources, and by utilizing renewable energy or CCS, it can act as carbon-free energy
- Converting surplus electricity from renewable energy sources into hydrogen enables long-term, large-scale energy storage
- By changing the physical properties and state of hydrogen (e.g. liquefaction), it is possible to transport and carry large amounts over long distances

Provides effective solutions for various energy challenges arising from the expansion of renewable power	Can be a viable power source for transportation modes, such as trucks, buses, ships, and trains, where electrification is difficult	Can be an effective solution for industrial demand in sectors like oil refining, chemical, and steel production

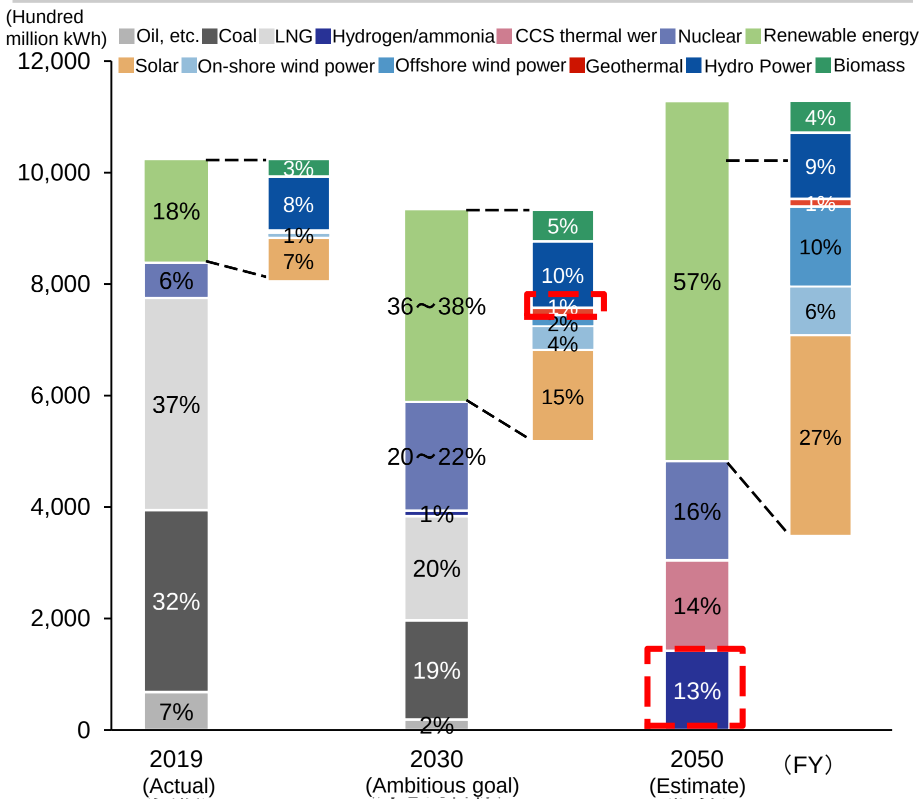
Hydrogen = Key to Achieving Carbon Neutrality

Source: Compiled by the Industry Research Division of Mizuho Bank.

Prospects for future power supply composition and hydrogen and ammonia use

- Estimates of electricity demand and power supply composition in 2050 assuming the electricity sector will be decarbonized.
  - These estimates assume maximum introduction of renewable energy and that nuclear power plants will be restarted and have their operational periods extended, with thermal power generation making up shortfalls.
- By 2050, we estimate that approximately 6 million tons of hydrogen and 16 million tons of ammonia will be used for hydrogen and ammonia power generation.

Prospects for power supply composition (2030 target and 2050 estimate)



Note: Mizuho Bank, "Envisioning Japan’s Industries in 2050: Structural Transformation and Industrial Fusion to Realize an Ideal Future," Mizuho Industrial Survey/70 (April 1, 2022).

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

Hydrogen and ammonia requirements in the power generation sector in 2050

(1) Power generation using hydrogen and ammonia

- Based on the estimates in the left chart, the total amount of electricity generated in 2050 will be about 1,100 billion kWh.
- Electricity from hydrogen and ammonia: 1,100 billion kWh x 13% = 140 billion kWh

(2) Remaining future installed capacity of gas- and coal-fired power

Assuming an operating life of 40 years (50-60 years for older power plants), the remaining gas- and coal-fired power generation capacity by 2050 is:

- Gas (≈ hydrogen fired or with added CCS in 2050): approx. 30 million kW
- Coal (≈ hydrogen fired or with added CCS in 2050): approx. 9 million kW

(3) Amounts of electricity generated by hydrogen and ammonia respectively

Assuming that hydrogen and ammonia power is used in the same proportion as the remaining gas- and coal-fired power capacity:

- Hydrogen: 140 billion kWh x 30 million kW / (39 million kW) = 100 billion kWh
- Ammonia: 140 billion kWh x 9 million kW / (39 million kW) = 40 billion kWh

(4) Demand for hydrogen and ammonia

The amounts of hydrogen and ammonia required for power generation is:

- Hydrogen: Power generation 100 billion kWh / Hydrogen heat release value 120 MJ/kg / Power generation efficiency 57% = approx. 6 million tons
- Ammonia: Power generation 40 billion kWh / Ammonia heat release 18.6 MJ/kg / Power generation efficiency 43% = approx. 16 million tons (hydrogen equivalent 3 million tons)

Note: 1kWh = 3.6MJ

Power companies' efforts to commercialize hydrogen and ammonia power generation

- Power companies are working on demonstrating hydrogen and ammonia power generation to achieve carbon neutrality for thermal power plant.
- JERA plans to start large-scale co-firing of fuel ammonia at the Hekinan Thermal Power Plant in FY2023 and simultaneously conduct international competitive bidding for fuel ammonia procurement.
- Kansai Electric Power is advancing efforts towards realizing hydrogen power by utilizing existing power plants.

JERA's efforts to realize ammonia power generation

[Schedule for ammonia co-firing demonstration project at Hekinan Thermal Power Plant]

	FY2021	FY2022	FY2023	FY2024
Demonstration Project Milestones	Small-scale ammonia co-firing at Unit 5		Ammonia demonstration First intake	Ammonia at Unit 4 Large-scale mixed firing
Modified burner installation work	Basic design	Detailed design	Installation work	
Tank installation work	Basic design	Base improvements; Civil/mechanical engineering		
Piping and other ancillary equipment installation work	Detailed design	Base improvements; Civil engineering, construction and mechanical engineering		

[Conduct international competitive bidding for fuel ammonia procurement]

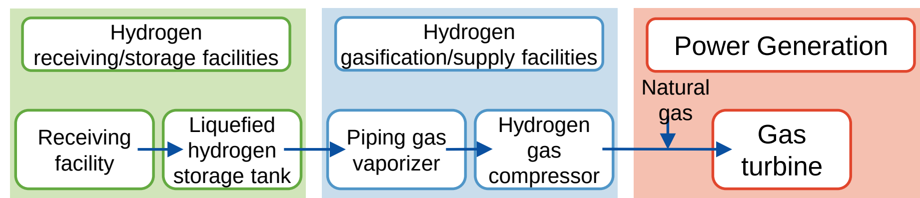
- Request for proposal sent to approximately 30 companies with bidding terms and conditions
- Supply period: Long-term contract from FY2027 to the 2040s
- Quantity: Up to 500,000 tons/year
- Other conditions: Must be blue/green ammonia

Opportunity for JERA to participate in manufacturing projects

Source: Compiled by Mizuho Bank, Ltd. Industry Research Department from company press releases.

Kansai Electric Power Company's efforts to realize hydrogen power generation

[Project Scope (image)]



[R&D period]

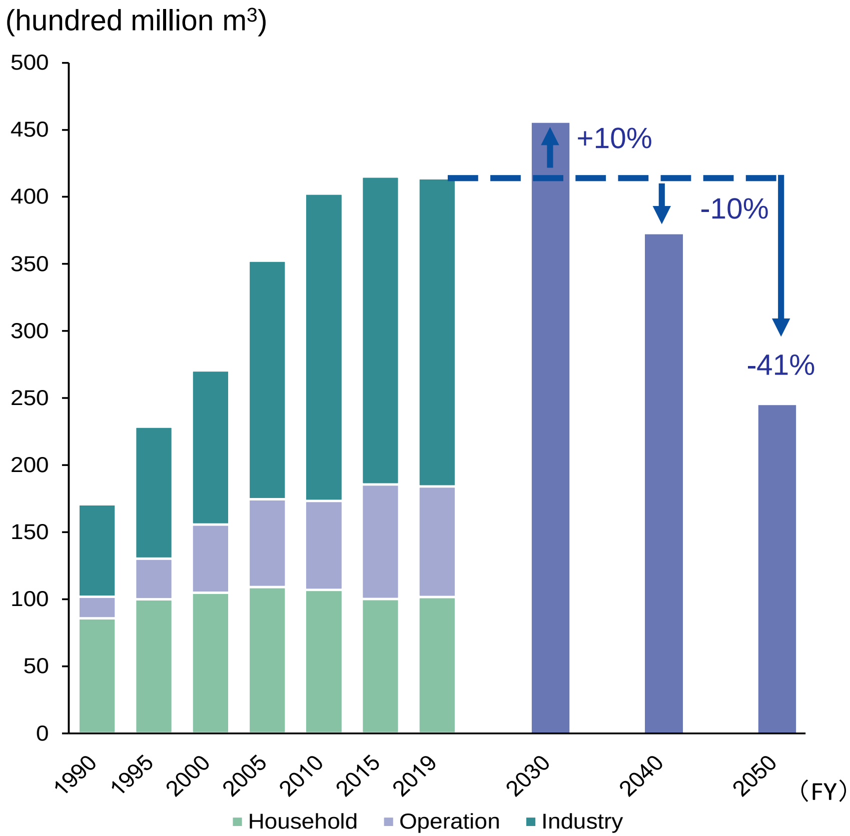
FY2021	FY2022	FY2023	FY2024	FY2025	FY2026	FY2027 onwards
FS Phase		Design/production phase		Demonstration phase		Commercialization study
• Conduct detailed study ✓ Verification items for hydrogen power generation demonstration ✓ Anticipated technical issues ✓ Scope of modifications to existing thermal power plants ✓ Project cost		• Based on the plant manufacturer's technology, detailed design, fabrication, and installation of related equipment will progress sequentially		• Demonstrate overall hydrogen power generation operation technology using existing gas turbine power generation equipment		• Consider commercialization based on results of demonstration

Source: Compiled by Mizuho Bank, Ltd. Industry Research Department from company press releases.

Prospects for using hydrogen to decarbonize the gas industry

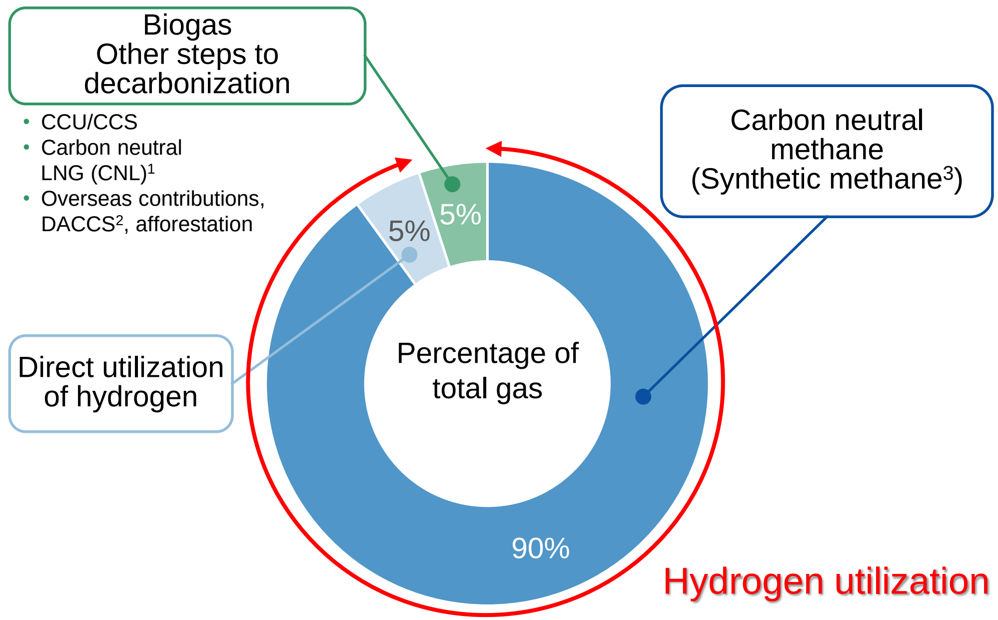
- Domestic demand for city gas supplies are projected to increase toward 2030, but decrease by about 40% in 2050 compared to 2019 due to the pressure to decarbonize.
- The Japan Gas Association aims to have carbon-neutral methane and hydrogen account for 90% and 5% of gaseous energy in 2050 respectively.

Domestic demand outlook for city gas, etc. (Mizuho's calculations)



Source: Compiled by Industry Research Department Mizuho Bank, Ltd. from the Agency for Natural Resources and Energy's Total Energy Statistics.

Gas carbon neutrality targets for 2050 (Japan Gas Association)



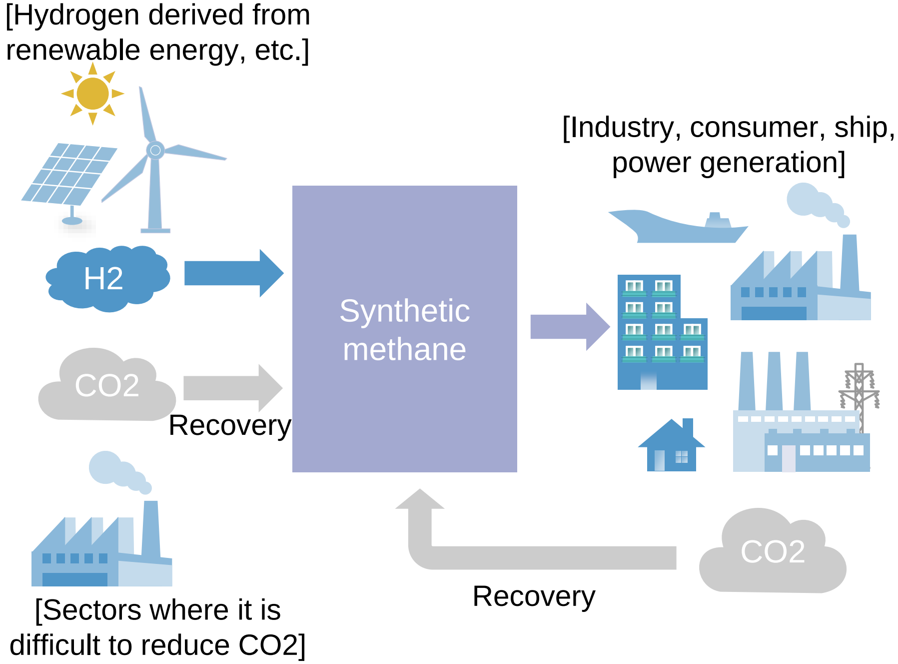
Note:
1. LNG (Liquefied Natural Gas) offsets the greenhouse gas emissions generated from the process of natural gas extraction to combustion through measures such as forest regeneration, which supports CO2 reduction.
2. Direct Air Carbon Capture with Storage (CO2 direct capture and storage technology).
3. Methane synthesized from decarbonized hydrogen and CO2.
4. Figures in the graph are an example of what would be achieved if innovation proceeds smoothly.
5. Assumption that hydrogen and CO2 are linked to policies, etc. and are economically and physically accessible.

Source: Compiled by Industry Research Department Mizuho Bank, Ltd. from Japan Gas Association's "Carbon Neutral Challenge 2050."

Oil and gas companies' efforts towards introducing synthetic methane

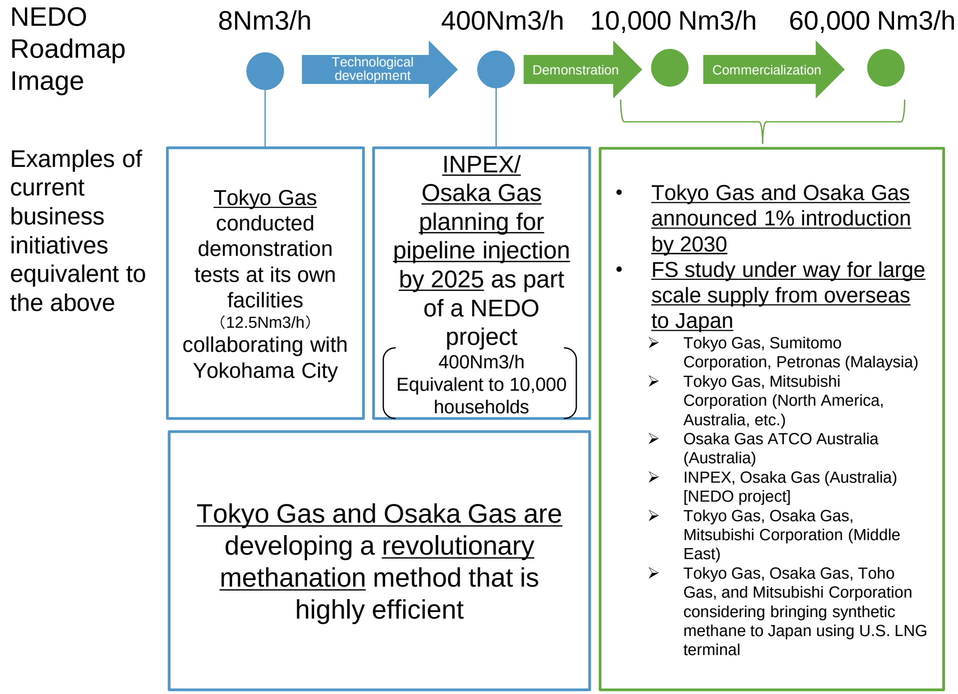
- Synthetic methane is a fuel produced by synthesizing (methanation) hydrogen and CO2, and it is a form of renewable energy and hydrogen utilization.
- Since the raw material is CO2 emitted during combustion in factories, etc., and no additional CO2 is emitted, which is classified as contributing to low carbon and carbon neutrality.
- Oil and gas companies are working on demonstration projects, with plans to inject synthetic methane into pipelines as early as 2025, but scaling up will take time.

Image of synthetic methane production



Source: Compiled by Industry Research Department Mizuho Bank, Ltd. from materials from the 7th Public-Private Council for the Promotion of Methanation.

Efforts to introduce and expand the use of synthetic methane



Source: Compiled by Industry Research Department Mizuho Bank, Ltd. from materials from the 7th Public-Private Council for the Promotion of Methanation.

Prospects for FC trucks/buses and hydrogen

- By 2030, the adoption of fuel cell electric vehicles (FCEVs) is expected to be limited due to differences in vehicle prices and maintenance costs. FCEVs will mainly be introduced in large trucks and buses, while battery electric vehicles (BEVs), which have a smaller total cost of ownership (TCO) difference, will be adopted in advance as zero-emission vehicles.
- By 2050, it is assumed that almost all new truck/bus sales will be FCEVs due to the reduction in hydrogen fuel costs. However, improvements in hydrogen fuel efficiency are expected to result in hydrogen consumption being only about half of the potential demand projected by the government.

Prospects for introduction of FC trucks/buses and hydrogen consumption (Mizuho's estimate)

		Large trucks	Medium-size trucks	Small trucks	Large buses	Small buses
Year of parity in FCEVs TCO prices	vs. diesel	2033	2035	2043	2033	2047
	vs. BEVs	2030	2032	2043	2029	2040
FC penetration prospects for 2030	Share of sales volume	24.1%	11.0%	0%	31.4%	0%
	Share of vehicles owned	1.4%	0.7%	0%	1.5%	0%
	Hydrogen consumption	7,000 tons/year				
FC penetration prospects for 2050	Share of sales volume	100%	100%	94.2%	100%	95.6%
	Share of vehicles owned	99.8%	95.9%	42.1%	89.6%	47.0%
	Hydrogen consumption	3.29 million tons/year (Note: Potential hydrogen demand for trucks: 6 million tons)				

- ✓ By 2030, the adoption of FCEVs is expected to be limited to large trucks and buses, resulting in a small number of vehicles and low hydrogen consumption.
- ✓ By 2050, significant reductions in hydrogen fuel costs are expected to make FCEVs the most advantageous option in terms of TCO, with almost all new car sales being FCEVs.
  - However, due to a decrease in the number of vehicles owned as a result of reduced transport ton-kilometers and improvements in hydrogen fuel efficiency, hydrogen consumption is expected to be only about half of the potential amount projected by the government.

Source: Compiled by the Industry Research Division of Mizuho Bank.

Prospects for hydrogen and ammonia on ships

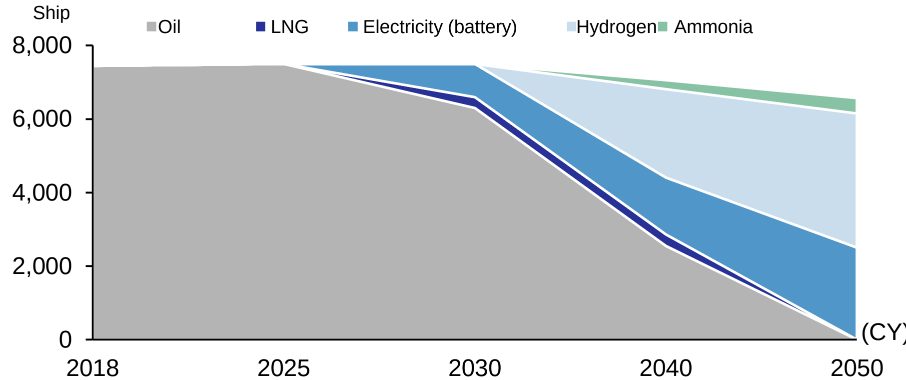
- To achieve carbon neutrality in the maritime sector, it is necessary to convert ship propulsion systems to electric power or zero-emission fuels.
  - — Each option has its own advantages and disadvantages, and the transition to zero-emission fuels is influenced by the progress made in addressing technical challenges.
- It is expected that hydrogen-fueled ships will become more common for domestic shipping, while ammonia-fueled ships will be more prevalent for international shipping.

Direction of zero emissions in the maritime sector (Mizuho's hypothesis)

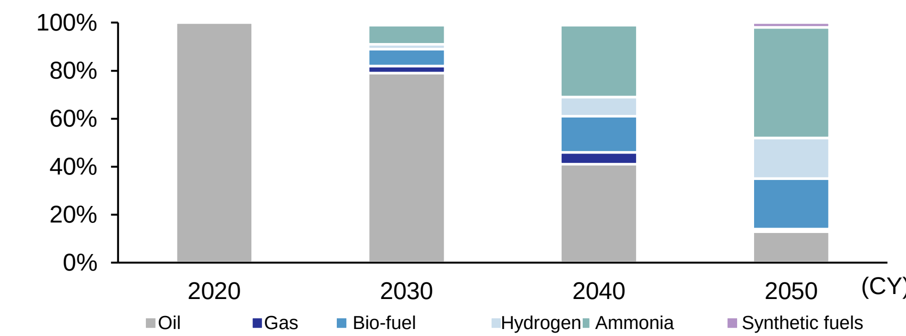
Fuel	Power source	Coastal vessels (small)	Coastal vessels (medium and large)	Ocean-going vessels	Challenges
Power	Batteries	◎	△ (Hybrid)	-	✓ Low energy density ✓ Long charging time
Hydrogen	Fuel Cell	◎	Depends on progress of higher output / lower cost		✓ Requires infrastructure development and legislation
Hydrogen	Internal-combustion engines	Depends on progress in addressing technical issues			✓ Requires infrastructure development and legislation
Ammonia	Internal-combustion engines	Depends on progress in addressing technical issues		◎	✓ Treatment of NOx
Carbon recycled methane	Internal-combustion engines	Fuel supply/depends on CO2-free method			✓ Existing LNG infrastructure can be converted ✓ Whether CO2-free is considered or not

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

Outlook for number of coastal vessels by fuel type



Outlook of market share by fuel type for ocean-going vessels

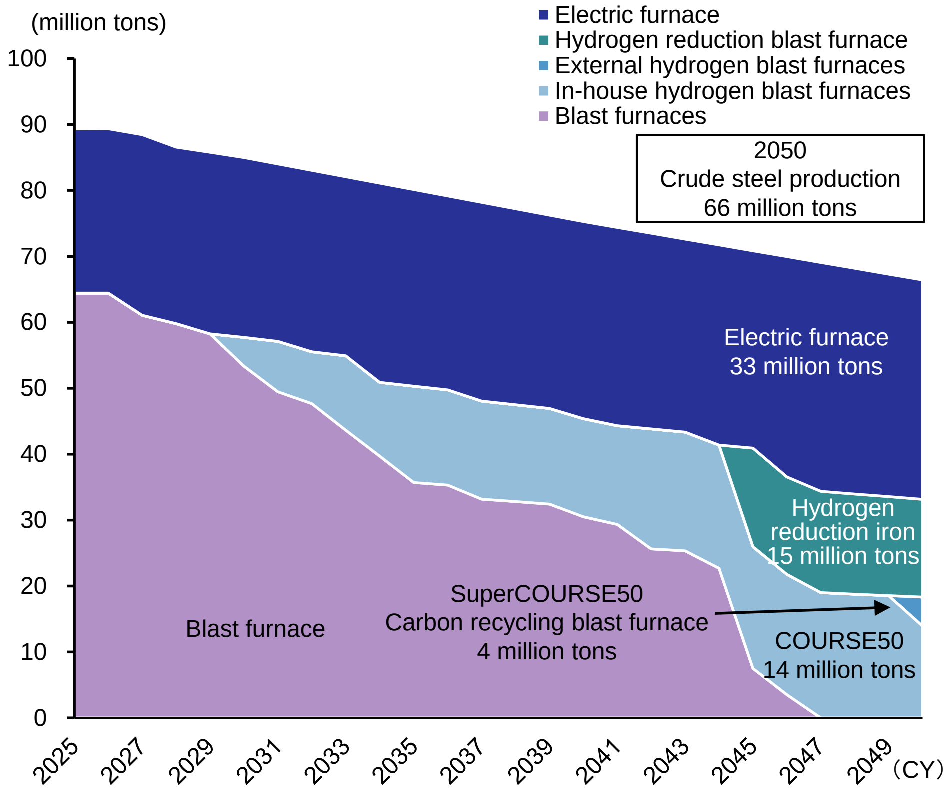


Source: Compiled by the Industry Research Division of Mizuho Bank, based on materials from the Nippon Foundation, IEA, and Net Zero by 2050.

Prospects for hydrogen use in the steel industry

- Assuming that the development and implementation of innovative technologies for carbon neutrality progress according to the technology roadmap and that new technologies are adopted during blast furnace modifications, by 2050, hydrogen reduction combined with scrap electric furnaces could account for 48 million tons, while blast furnace usage could be 18 million tons.
- The estimated hydrogen procurement for reducing agents in 2050 is 1.44 million tons (although hydrogen reduction is an endothermic reaction, hydrogen as a potential heat source to increase the furnace temperature is not considered).

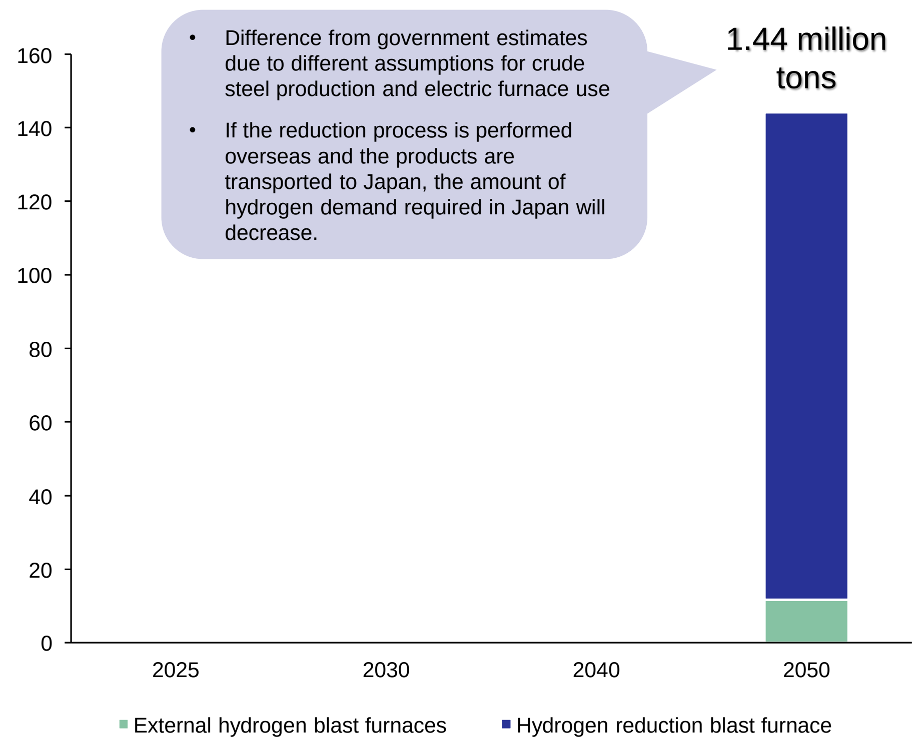
Crude steel production simulation per-furnace type



Note: Shifted to a newly developed technology or halted when renewing blast furnaces' petrochemical complex every 20 years. Adjacent or CN port adjacent steel mills move to hydrogen reduction, otherwise to electric furnaces.

Source: Compiled by the Industry Research Division of Mizuho Bank.

Simulation of external hydrogen procurement

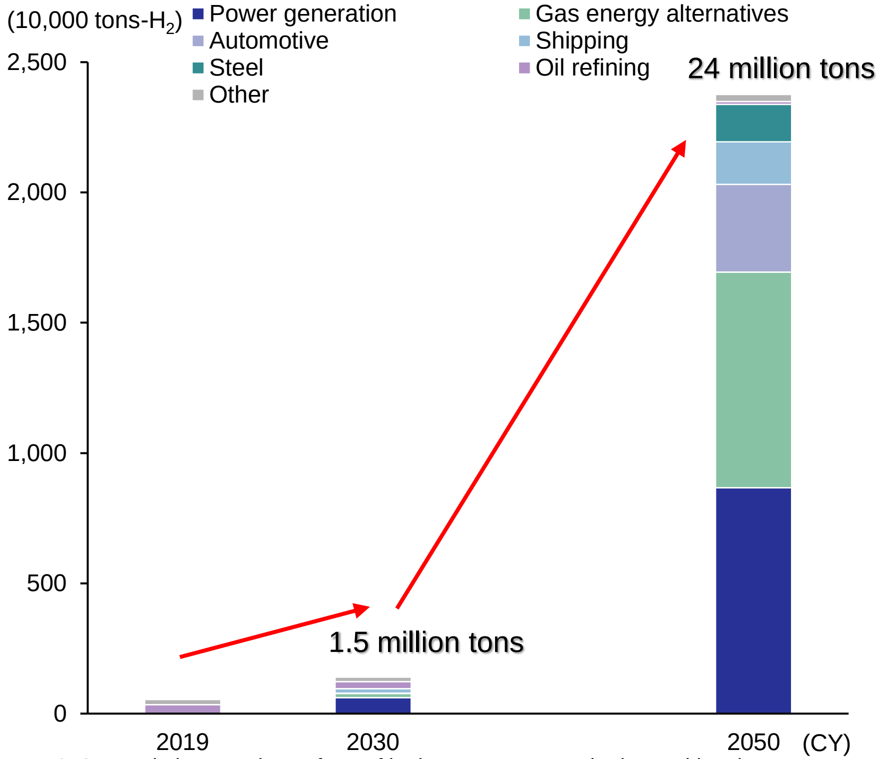


Source: Compiled by the Industry Research Division of Mizuho Bank.

Outlook for domestic hydrogen demand in 2050

- In Japan, by 2050, the demand for hydrogen is expected to reach around 24 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 substitution, automobiles, steel, and shipping.
  - 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.

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



Note: 1. Ammonia is treated as a form of hydrogen, so ammonia demand has been converted to that of hydrogen.
2. Vessels include both domestic and international vessels.

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

Key points of demand outlook through to 2050

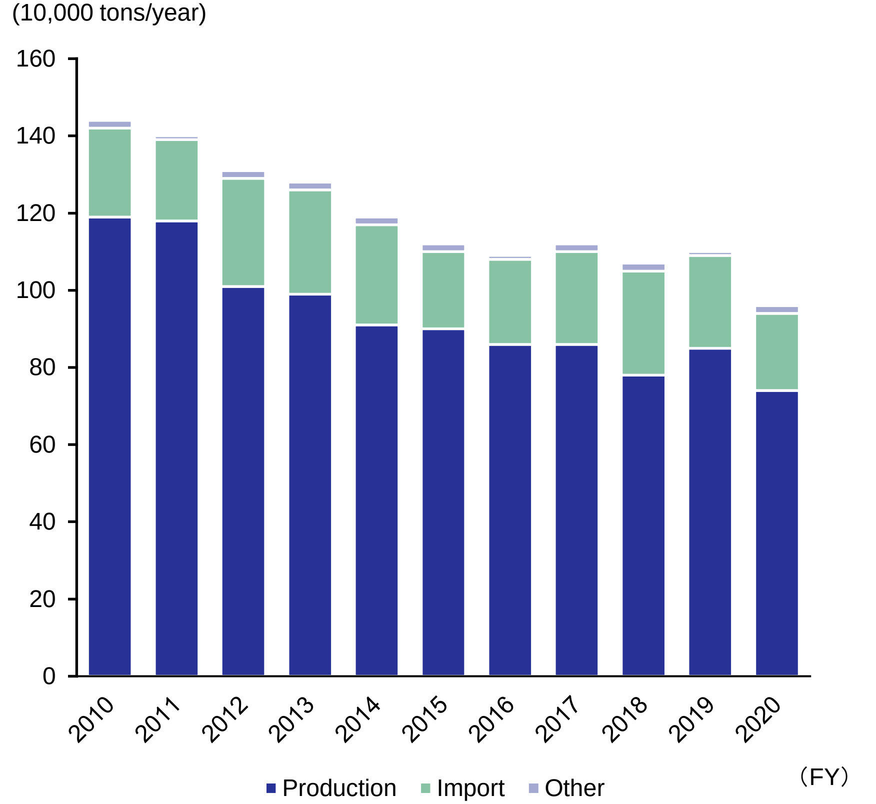
Steel	• By partially transitioning from blast furnaces using coal to SuperCOURSE50 carbon recycling blast furnaces and hydrogen reduction steelmaking, demand will emerge for externally procured hydrogen
Ships	• Hydrogen and ammonia demand will emerge due to the conversion to hydrogen and ammonia-fueled ships
Automotive	• Partial shift from gasoline and diesel vehicles to FCEVs 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 Basic 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 dedicated power generation will make up 13% of the power supply composition

Source: Compiled by the Industry Research Division of Mizuho Bank.

Current ammonia supply and demand trends

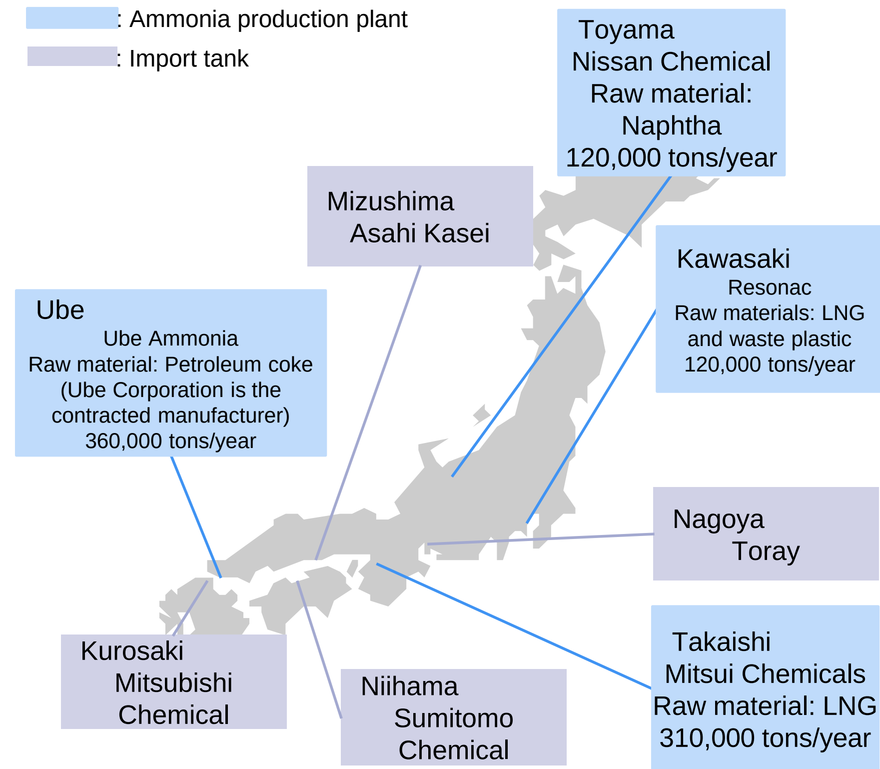
- Currently, ammonia is mainly used as a chemical raw material for fertilizers and other applications, with most demand being met by domestic production.
- Ammonia-related infrastructure is owned by chemical manufacturers, and it is assumed that most of the ammonia is derived from fossil fuels.
- In the future, utilization as a hydrogen carrier and fuel, which are different from traditional applications, is expected.

Changes in ammonia demand



Source: Compiled by Industry Research Department Mizuho Bank, Ltd. based on materials from the Japan Fertilizer & Ammonia Producers Association.

Ammonia infrastructure positioning in Japan (as of July 2022)



Source: Compiled by Industry Research Department Mizuho Bank, Ltd. based on materials from the Japan Fertilizer & Ammonia Producers Association.

Background and precautions regarding ammonia as a hydrogen carrier and fuel

- Ammonia is attracting attention as a hydrogen carrier and a zero-emission fuel.
- As a fuel, ammonia has advantages over hydrogen, such as the possibility of low-cost utilization and the existence of a small-scale international supply chain as a raw material chemical.
- However, precautions are required regarding its toxicity and the difficulty of achieving stable combustion.

Why ammonia usage is attracting attention

Use as a carrier

1. Can be used as a carrier to efficiently transport hydrogen, which is difficult to transport in large volumes

Use as fuel

2. Does not emit CO2 during combustion so can be used as a zero-emission fuel
3. Ammonia power generation may be lower in cost than hydrogen according to estimates by government
4. International supply chain exists as a raw material for chemical (accumulated know-how on handling)
5. Utilities and heavy electric manufacturers have already demonstrated ammonia power generation, and mixed combustion technologies are on-track for use by the mid-2020s

Source: Compiled by the Industry Research Division of Mizuho Bank.

Precautions regarding ammonia usage

Use as a carrier

1. A dehydrogenation process is required to extract the hydrogen (additional costs and processes are required) → Reduced dehydrogenation costs are needed

Use as fuel

2. Ammonia is toxic and requires safety measures such as preventing leaks
3. Combustion speed is slower than hydrogen and stable combustion is difficult

→ (2, 3) Technical skills required to handle

4. Nitrogen oxide is generated during combustion → Measures to reduce nitrogen oxide emissions are needed

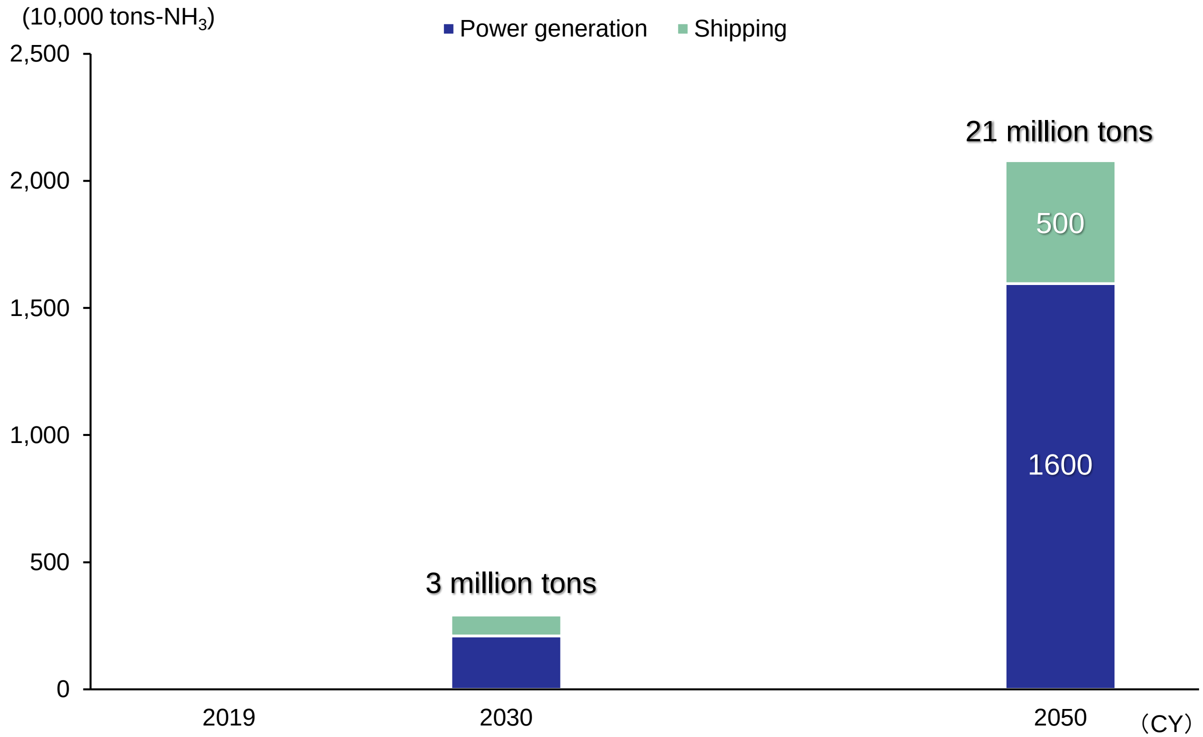
Considering the cost of dehydrogenation and the need to deal with hazardous substances, its main applications are electric power and ships, where ammonia can be directly combusted.

Source: Compiled by the Industry Research Division of Mizuho Bank.

Domestic fuel ammonia demand outlook through to 2050

- In Japan, fuel ammonia will mainly be used for decarbonizing coal-fired power, with demand expected to exceed 20 million tons annually by 2050.
- Due to geographical constraints such as limited renewable energy sites and the lack of interconnection with other countries, Japan will continue to rely on thermal power generation, resulting in a high demand for ammonia co-firing and dedicated firing.
  - Power companies are currently preparing for commercial use, and large-scale utilization is expected to take off in the near future.

Fuel ammonia demand forecast (domestic, approximate)



Note: 1. Ammonia demand is calculated in terms of weight and is also included in the hydrogen demand mentioned in the previous section.
2. The demand for ammonia in the shipping sector includes both domestic and international vessels.

Source: Compiled by the Industry Research Division of Mizuho Bank.

Potential prospects for green hydrogen supply in Japan

- Japan has limited reserves of fossil fuels and renewable energy resources, limiting the domestic CO2-free hydrogen production potential.
- According to calculations by the Agency for Natural Resources and Energy, the maximum production capacity would be 4.7 million tons if all surplus renewable energy were used for hydrogen production.
  - To meet the demand in 2050, Japan will need to rely on a significant amount of imports from overseas.
- In reality, it is not guaranteed that all surplus renewable energy will be used for hydrogen production, but further hydrogen production is possible through the use of nuclear power (yellow hydrogen).
  - There is potential for domestic blue hydrogen production, but its production capacity depends on the availability of suitable sites for CCS, which is uncertain.
  - From 2023 onwards, there are movements to restart nuclear reactors and develop next-generation nuclear reactors, which could potentially increase hydrogen production capacity in the future.

Green hydrogen production potential using surplus renewable energy in Japan from 2040

	Uneven power supply scenario (30GW)	Uneven power supply scenario (45GW)	Change of power supply location scenario (45GW)	Renewable energy = 50 to 60% scenario
Investment in grid enhancements	2.2 trillion to 2.7 trillion yen	3.8 trillion to 4.8 trillion yen	1.5 trillion to 1.7 trillion yen	2.0 trillion to 2.6 trillion yen
Renewable energy ratio	37%	42%	42%	53%
Renewable energy output control rate	2%	4%	4%	39%
Surplus renewable energy	7 billion kWh	16 billion kWh	16 billion kWh	200 billion kWh ≈ 4.7 million tons of hydrogen can be produced

Hydrogen will need to be imported from overseas to meet domestic demand in 2050

- ✓ If surplus renewable energy is used for purposes other than hydrogen production, the amount of hydrogen produced will decrease
- ✓ If hydrogen production using nuclear power (yellow hydrogen) is realized or dedicated renewable energy facilities for hydrogen production are constructed, the amount of hydrogen produced will increase
- ✓ There is potential for domestic blue hydrogen production, but its production capacity depends on the availability of suitable sites for CCS, making the hydrogen production potential uncertain

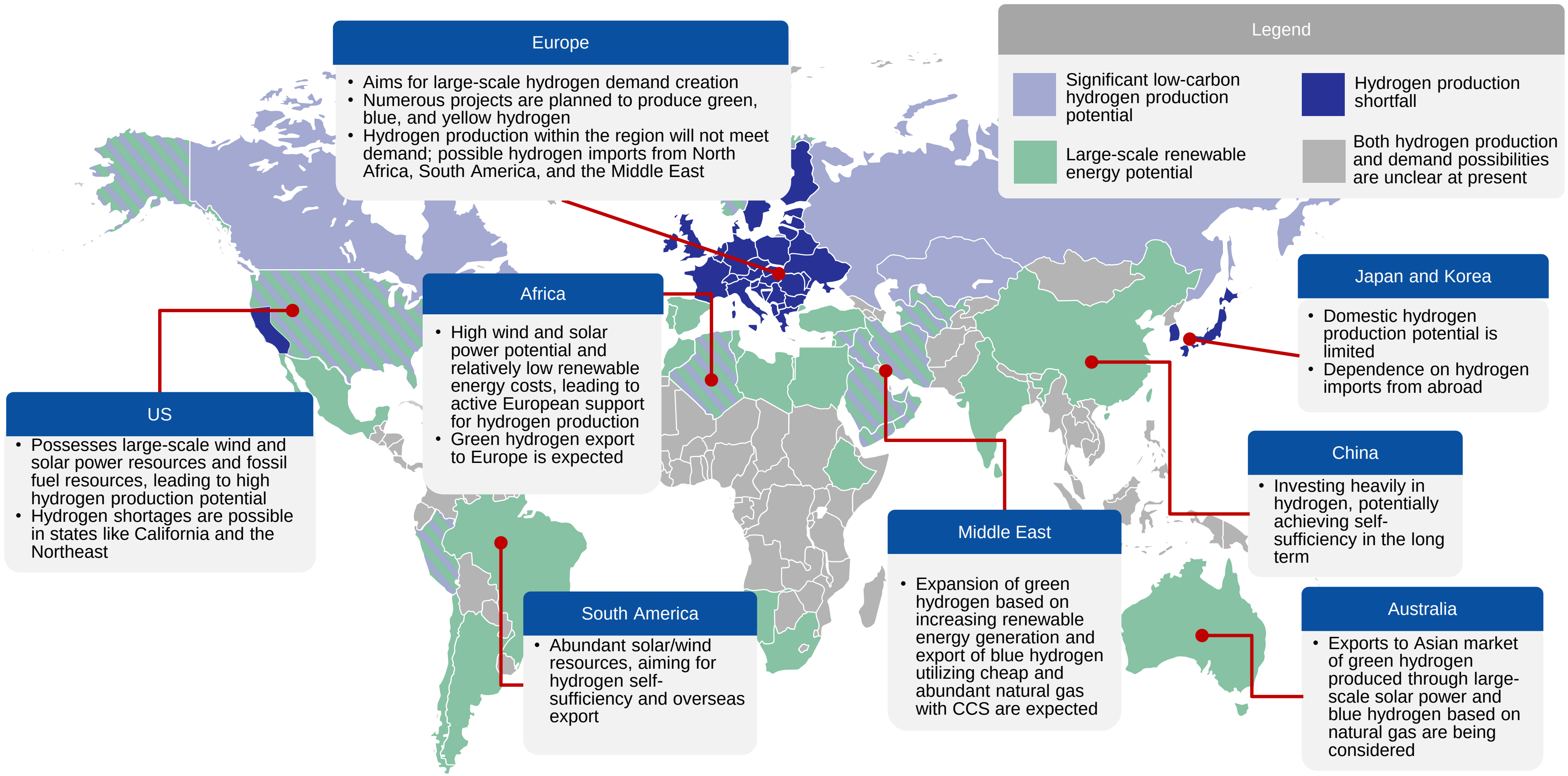
Note: Surplus renewable energy is calculated assuming that the total amount of electricity generated is unchanged in each scenario.

Source: Compiled by Industry Research Department Mizuho Bank, Ltd. from information from the Organization for Cross-regional Coordination of Transmission Operators' "Master Plan - Interim Report" and the Agency for Natural Resources and Energy's "2nd Hydrogen Policy Subcommittee" materials.

Global supply and demand map for hydrogen

- As hydrogen is expected to become an important energy source in the future, a supply-demand gap is expected to emerge in various countries and regions. There will therefore likely be competition between countries and regions that are looking to make hydrogen an export industry and countries and regions that want to procure hydrogen stably and cheaply.

Prospects for hydrogen supply and demand trends in various countries and regions



Source: Compiled by Industry Research Department Mizuho Bank, Ltd. based on various press materials and the Canadian “Hydrogen strategy for Canada.”

Global competition for hydrogen is intensifying

- In response to the trend of decarbonization, various countries and regions, starting with Europe, have formulated hydrogen strategies and invested heavily in government budgets to promote hydrogen energy shifts and hydrogen industry promotion. The competition for hydrogen is intensifying.

Trends in hydrogen policies, in each country/region

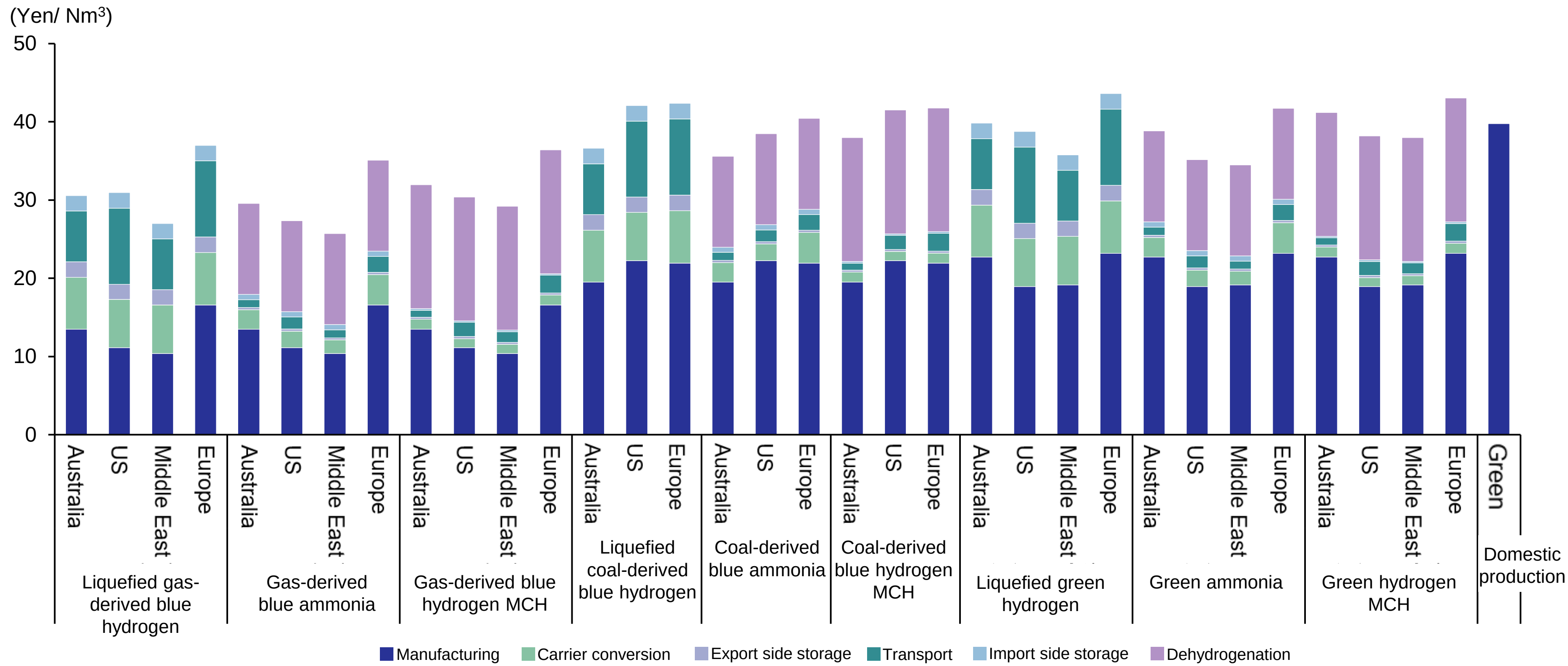
Country/region	Trends
EU (European Union)	✓ Formulated the "European Hydrogen Roadmap" in 2019 and the "European Hydrogen Strategy" in 2020 ✓ Announced "REPowerEU" in 2022, considering the situation in Russia and Ukraine, and set targets to produce 10 million tons/year of renewable hydrogen domestically and import 10 million tons/year from abroad (e.g. North Africa) by 2030, while revising the renewable energy directive to create demand
Germany	✓ Formulated a national hydrogen strategy in 2020, aiming to increase domestic renewable hydrogen production capacity to 5GW by 2030 ✓ Adopted grants of 7 billion euros for domestic market creation and 2 billion euros for building international partnerships in 2020
France	✓ hydrogen strategy revised in 2020, aiming to increase electrolysis equipment to 6.5GW by 2030, for production of hydrogen from renewable and nuclear sources
UK	✓ A national hydrogen strategy formulated in 2021which announced that 5GW of low-carbon hydrogen production capacity developed by 2030 and hydrogen will account for 20-35% of the UK's final energy consumption by 2050 ✓ In 2022, in response to the Russia-Ukraine situation, an energy security strategy that doubles the 2030 production capacity target to 10GW, with at least half to be sourced from electrolytic hydrogen was announced
US	✓ At the national level, the Department of Energy (DOE) leads H2@Scale PJ, which has considered basic research to applied development, and announced its hydrogen program plan will aim to reduce the cost of hydrogen production and transportation to $2/kg each and $1/kg for industrial and power generation applications by 2020 ✓ In 2020, California formulated a deployment and construction roadmap for renewable hydrogen production facilities, announcing that the demand for green hydrogen would reach 400,000 tons/year by 2030 and 4 million tons/year by 2050
China	✓ Currently the world's largest hydrogen producer with over 95% gray hydrogen, plans to increase the green hydrogen share to 15% by 2030 and 70% by 2050 ✓ Formulated a hydrogen roadmap for vehicles, ships, and railways, and created a green hydrogen certification system as part of its energy law in December 2020; numerous hydrogen development plans also exist at the local government level
South Korea	✓ Announced a hydrogen roadmap in 2019 and a 2050 carbon neutral promotion strategy in December 2020 ✓ In 2021, 15 major South Korean companies launched a Korea hydrogen business summit and announced an investment of over 4 trillion yen by 2030
Australia	✓ Released a hydrogen roadmap in 2018 and a national hydrogen strategy in 2019 ✓ Outlined 57 action plans to lead the global hydrogen industry by 2030, with state governments supporting projects through funding
Saudi Arabia	✓ In 2021, the Energy Minister announced plans to produce and export 4 million tons/year of hydrogen by 2030, with Saudi Aramco's CEO stating the intention to secure long-term supply contracts in major markets and considering exports to Europe via pipelines ✓ In 2020, ACWA Power, Air Products, and a local company agreed to construct a plant producing over 200,000 tons/year of green hydrogen and 1.2 million tons/year of green ammonia, with Thyssenkrupp set to supply the electrolysis equipment
UAE	✓ In 2021, announced a goal of achieving a 25% share of the global hydrogen market by 2030, with plans to export to Europe and East Asia ✓ Abu Dhabi National Oil Company (ADNOC) plans to increase its hydrogen production from its current level of over 300,000 tons/year to 500,000 tons/year

Source: Compiled by Industry Research Department Mizuho Bank, Ltd. based on each country's hydrogen strategy and a variety of public information.

Hydrogen supply cost estimates for 2030

- Blue ammonia and blue hydrogen from the Middle East are highly competitive, followed by blue ammonia from the US.
  - Transport from Europe to Japan is relatively uncompetitive.
  - If ammonia is used as a fuel rather than a hydrogen carrier, the cost of dehydrogenation is eliminated, further increasing competitiveness.
- It is not assumed blue hydrogen would be produced in Japan due to the difficulty of securing suitable domestic CCS sites in 2030.

Comparison of hydrogen supply cost to Japan by production location (2030)



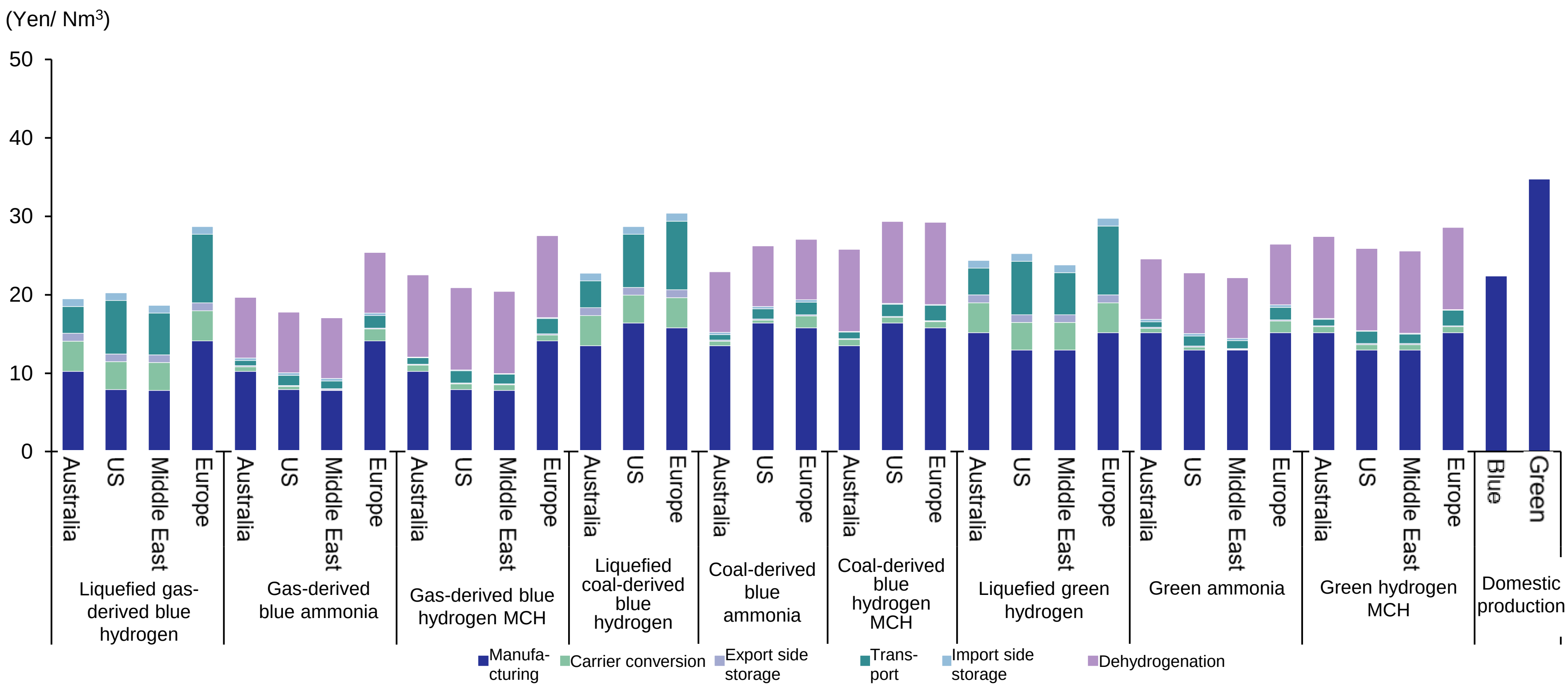
Note: 1. Transportation costs between hydrogen production sites and shipping terminals and between the hydrogen receiving site and the demand site were not taken into account.
2. Domestic production only considers production costs.

Source: Compiled by Industry Research Department Mizuho Bank, Ltd. From IEA's The Future of Hydrogen.

Hydrogen supply cost estimates for 2050

- Although the overall cost of hydrogen supply will decline due to mass production and lower energy prices, the competitiveness of blue ammonia/blue hydrogen from the Middle East and blue ammonia from the US will remain high. The competitiveness of blue hydrogen Australia will also improve.
- Lower electrolyzer prices and renewable electricity prices will bring the cost of green hydrogen closer to the price of blue hydrogen.
  - There is a possibility of price competitiveness equivalent to blue hydrogen if low-cost renewable energy of about 2 yen/kWh can be secured.

Comparison of hydrogen supply cost to Japan by production location(2050)



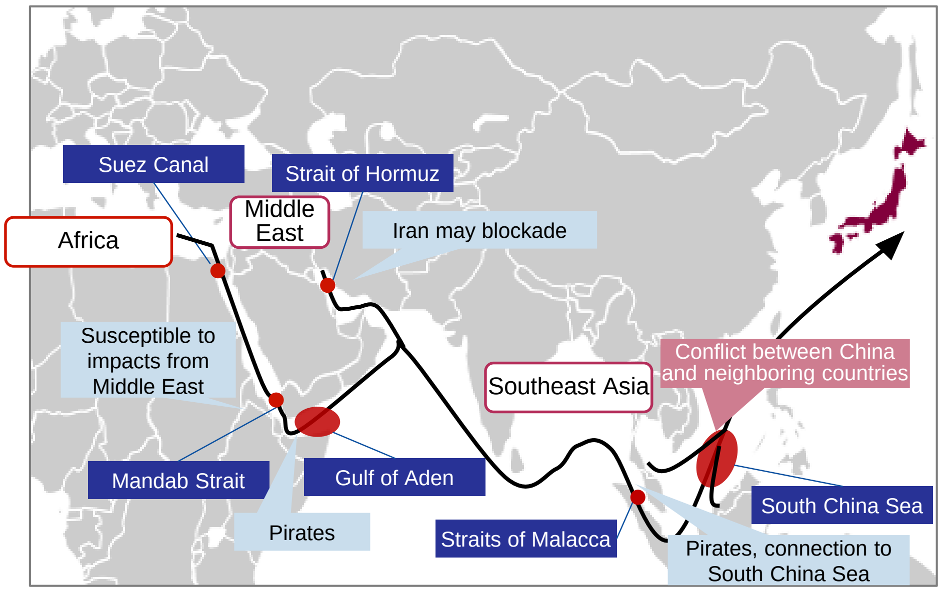
Note: 1. Transportation costs between hydrogen production sites and shipping terminals and between the hydrogen receiving site and the demand site were not taken into account.
2. Domestic production only considers production costs.

Source: Compiled by Industry Research Department Mizuho Bank, Ltd. From IEA's The Future of Hydrogen.

Choke point risks for Japan's hydrogen imports

- Securing choke point areas along import routes (i.e. narrow points where trade routes are concentrated) is vital for Japan as a maritime importer of hydrogen.
- When transporting hydrogen from the Middle East - , a possible source of procurement to Japan, ships will pass through three choke points: the Strait of Hormuz, the Strait of Malacca, and the South China Sea.

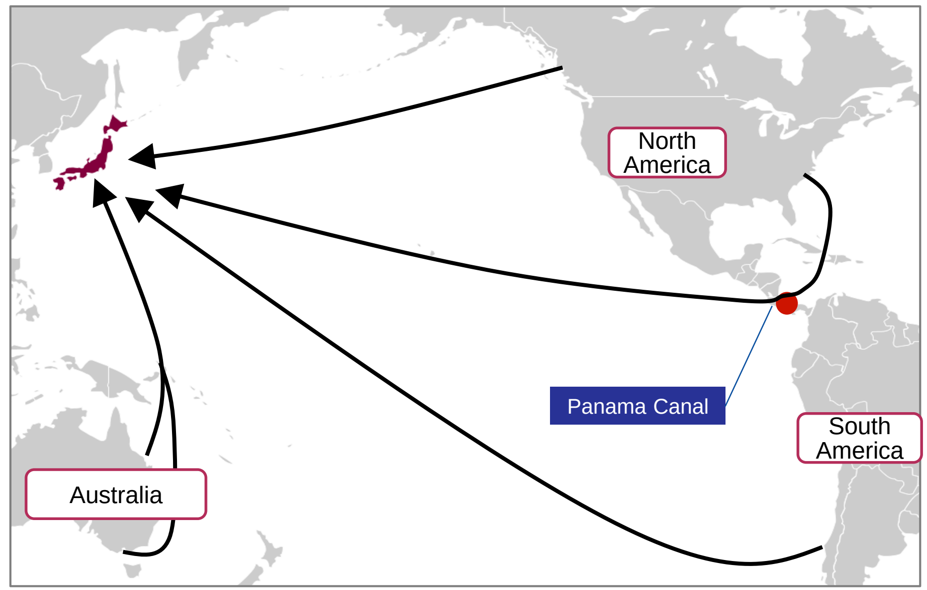
Choke points on North Africa, Middle East, and Southeast Asia routes



(Legend)

Name of choke point | Emerging risks

Choke points on North/South American and Australian routes



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

Summary: Concepts behind hydrogen for Japan

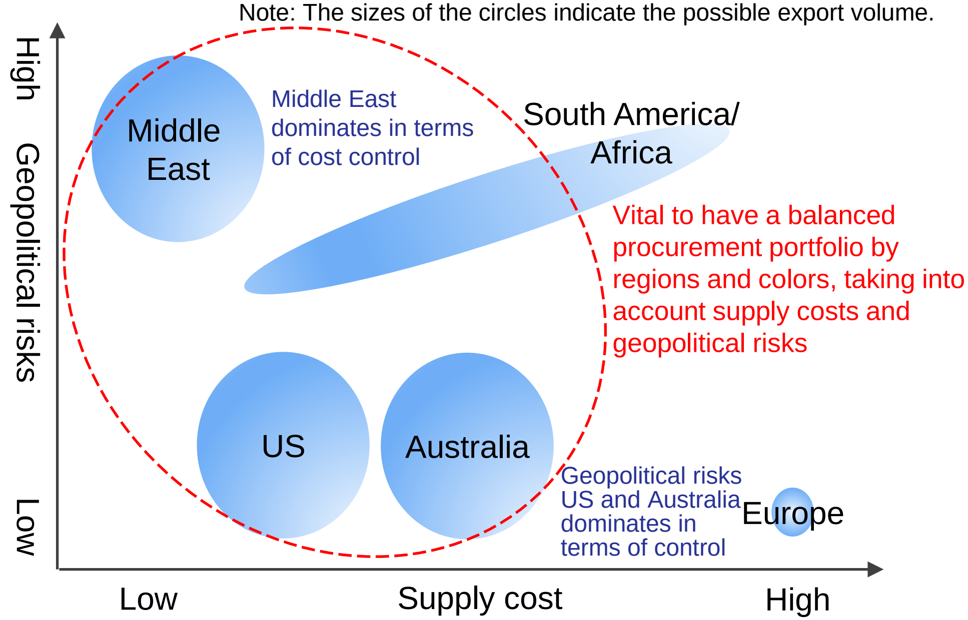
- In considering Japan's hydrogen procurement strategy, it is necessary to take into account not only the cost of supply from hydrogen surplus countries but also factors such as geopolitical risk reduction and color diversit.
- A well-balanced procurement portfolio should be established by regional sources diversification and types of hydrogen.

Characteristics of hydrogen procurement by country/region

Country/region	Hydrogen supply and demand	Supply cost	Geopolitical risks
Middle East	Excess supply	Low	High
North America	With some exceptions excess supply	Low	Low
Australia	Excess supply	Slightly low	Low
Europe	Excess demand	High	Low
Other	South America and Africa have excess supply	—	Slightly high to high

Mapping of each country

Note: The sizes of the circles indicate the possible export volume.



In addition to diversifying procurement countries, it is essential to advance hydrogen procurement that considers color diversity

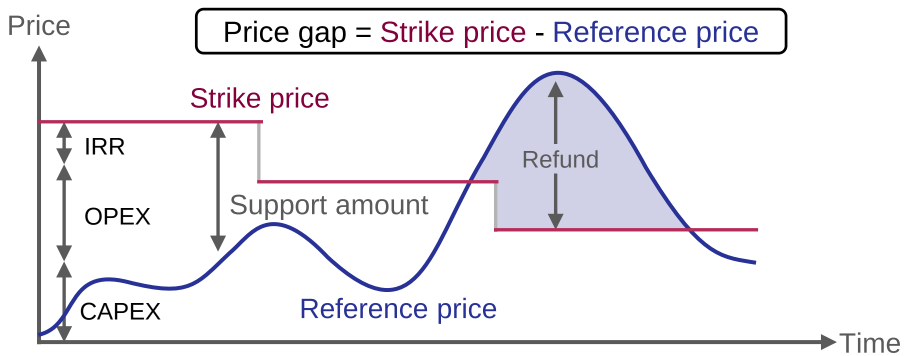
— While Middle Eastern blue hydrogen has cost advantages, there is a possibility that hydrogen supply to Japan may be halted if geopolitical risks materialize.
— To mitigate geopolitical risks, it is crucial to secure energy security through diversified procurement from countries such as the US and Australia.
— From the perspective of color diversity, efforts should be made to produce and procure not only blue hydrogen but also green, yellow, and turquoise hydrogen.
— Taking into account both geopolitical risk reduction and color diversity, it is also extremely important to increase hydrogen production within Japan.

Source: Compiled by the Industry Research Division of Mizuho Bank.

Future direction of support for hydrogen and ammonia: establishment of a large-scale supply chain

- In the future, support will be promoted from the viewpoint of building supply chains and forming supply bases.
- Compensation for the price gap between the strike and reference prices of hydrogen and ammonia are a the key element in supply chain building
  - In principle, the support period is 15 years.
  - In principle, clean hydrogen and ammonia are eligible for support targets

Overview of the contract for difference system



Strike price: The price per unit sold, at which the revenue generated at that level can reasonably cover the costs required for business continuity, and an appropriate profit is expected to be obtained (expected to be reviewed periodically).

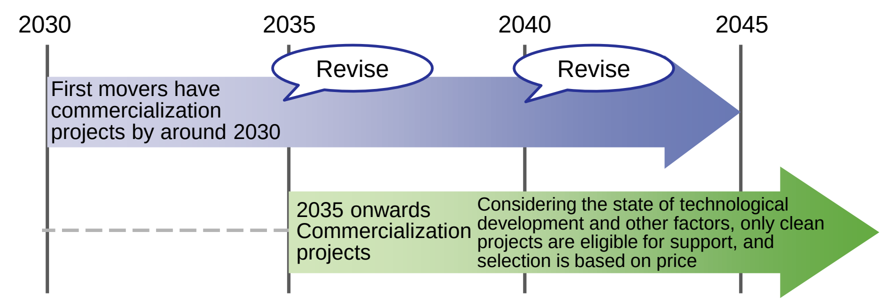
Reference price: Price set based on existing the parity price of fuel (see note). Hydrogen and ammonia are compared to LNG and coal prices, respectively.

> Support will be provided for the difference (either partially or fully) between the base price and the reference price for the hydrogen supplied by the business operators. Additionally, there are opportunities to review the base price based on actual performance and prospects at specific intervals (e.g. every 5 years).

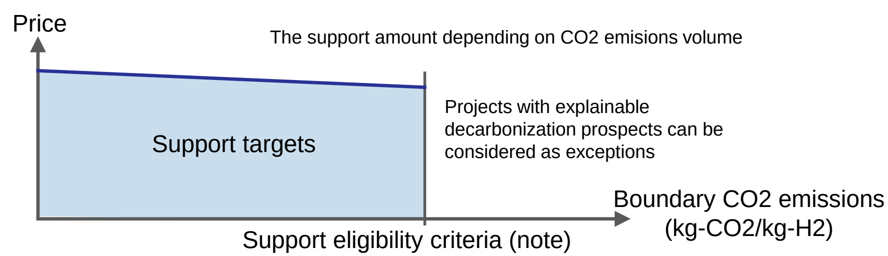
Note: Market price of fuel required to obtain the same amount of heat or work when compared to hydrogen, etc.
Source: Compiled by Industry Research Division Mizuho Bank, Ltd., based on interim data from the Agency for Natural Resources and Energy's 7th Joint Meeting of the Hydrogen Policy Subcommittee and the Subcommittee on Ammonia and Other Decarbonized Fuel Policies.

Duration and eligibility for the contract for difference system

- For selected first movers, the period of support will be 15 years (20 years depending on circumstances)



- In principle, clean hydrogen and ammonia are support targets

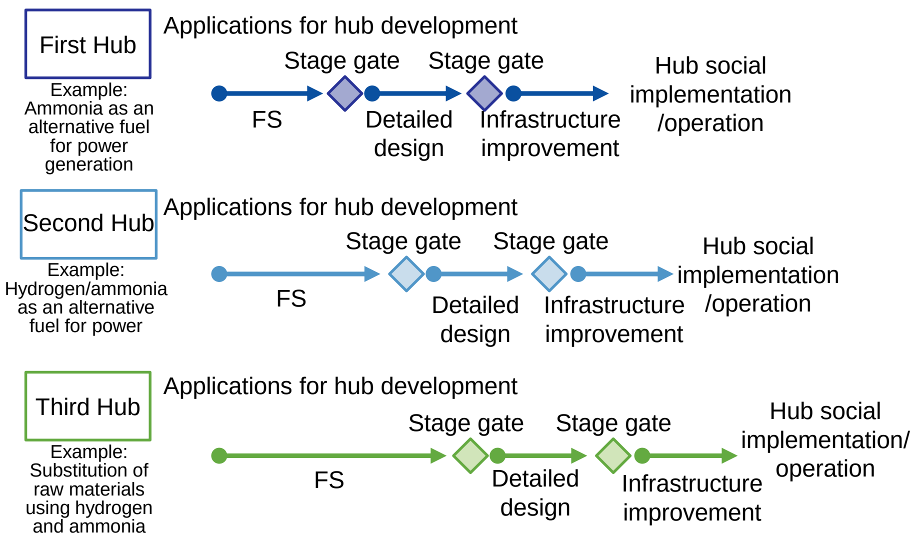


Note: Policy to set internationally comparable standards
Source: Compiled by Industry Research Division Mizuho Bank, Ltd., based on interim data from the Agency for Natural Resources and Energy's 7th Joint Meeting of the Hydrogen Policy Subcommittee and the Subcommittee on Ammonia and Other Decarbonized Fuel Policies.

Future direction of support for hydrogen and ammonia: Development of supply infrastructure

- Regarding the development of supply infrastructure, support will be provided for the establishment of hubs that promote internationally competitive industrial clusters.
- Over the next 10 years, plans are in place to develop approximately three large-scale hubs in metropolitan areas, and about five medium-scale hubs distributed across various regions.
  - — The support targets infrastructure shared by multiple companies.

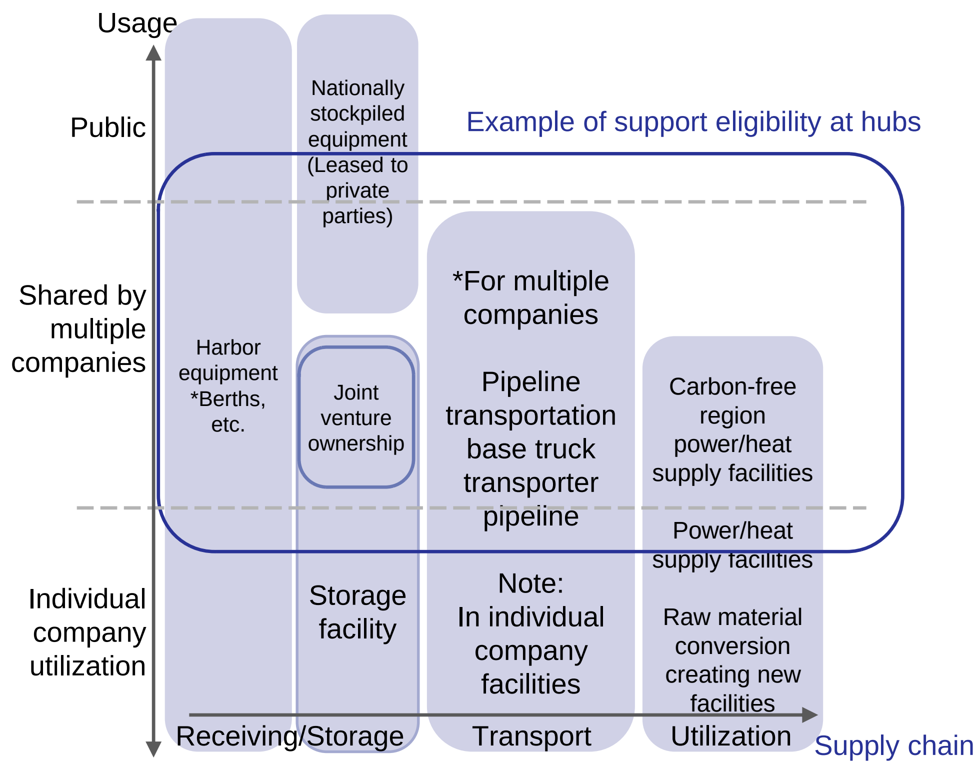
Support for development of supply infrastructure



- Support is provided in three phases: (1) feasibility study (FS) for hub development, (2) detailed design (FEED), and (3) infrastructure development. Promising sites will receive stage-gate and focused support, following the example of the GI Fund.
- Support for (3) Infrastructure development, will be provided within a certain period after the technology maturity level (TRL) of the technology to be used exceeds the implementation stage. Meanwhile, the periods for (1) FS support and (2) detailed design support will be provided before that time.

Source: Compiled by Industry Research Division Mizuho Bank, Ltd., based on interim data from the Agency for Natural Resources and Energy's 7th Joint Meeting of the Hydrogen Policy Subcommittee and the Subcommittee on Ammonia and Other Decarbonized Fuel Policies.

Image of infrastructure and facilities necessary to form a hub

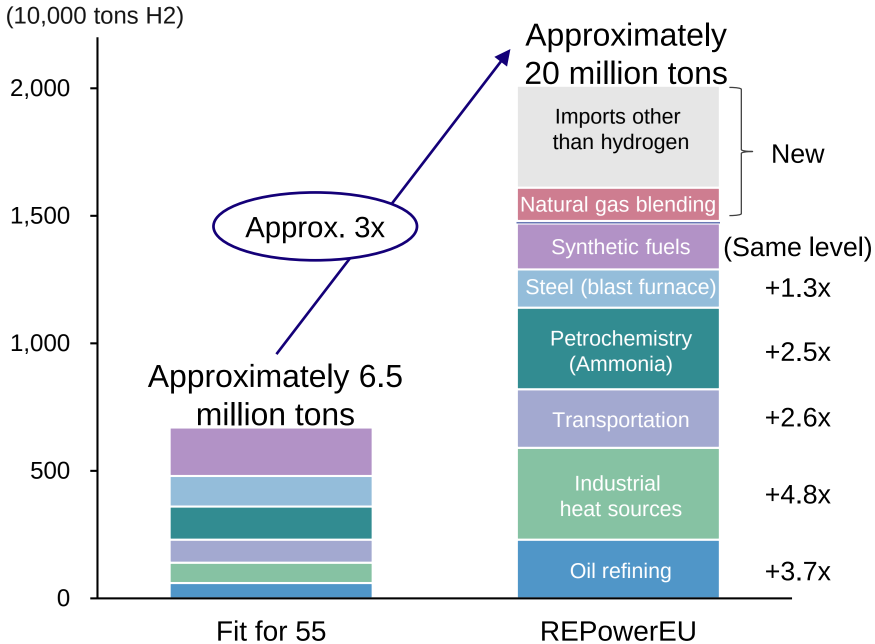


Source: Compiled by Industry Research Division Mizuho Bank, Ltd., based on data from the Agency for Natural Resources and Energy's 7th Joint Meeting of the Hydrogen Policy Subcommittee and the Subcommittee on Ammonia and Other Decarbonized Fuel Policies.

Europe: REPowerEU expected to significantly increase demand for hydrogen

- In REPowerEU, hydrogen demand for 2030 is expected to be around 20 million tons per year, approximately three times that of Fit for 55 (note). On the supply side, the goal is to secure 10 million tons per year of green hydrogen through both domestic production and imports.
- The European Commission has implemented a regulation in its taxonomy that considers hydrogen clean if it reduces CO2 emissions by more than 70% from production to consumption.
  - There is a possibility that the EU taxonomy standard for clean hydrogen production (assuming mainly blue hydrogen) could become an international standard.

Change in outlook for hydrogen use by sector (as of 2030)



Aim to secure green hydrogen supply of 10 million tons/year produced in the EU and 10 million tons/year imported by 2030.

Environmental standards for clean hydrogen production

- Currently, there are no comprehensive international standards on how much CO2 reduction qualifies hydrogen as clean.
- To attract investment in CO2-reducing technologies, the EU, the UK, and the US are taking the lead in clarifying standards and striving to be at the forefront of creating international standards.

Environmental standard	Content
CertiHy (Europe)	Reduce CO2 emitted at the manufacturing stage by 60% Standards expected to be raised in the future
EU taxonomy regulations	Reduce CO2 emitted from production through to transport and consumption as fuel by more than 70%
Low carbon hydrogen bill (UK)	Reduce CO2 emitted at the time of manufacture by 60%
[Reference] Infrastructure Act (US)	Reduce CO2 emitted at the time of manufacture by at least 80%

Many domestic companies are aware of the 60% reduction set by CertiHy, and hydrogen projects that do not meet Western standards are at risk of not being able to attract investment in the future.

Note: Greenhouse gas reduction targets for 2030 announced by the European Commission in 2021. Target 55% reduction from 1990 levels.
Source: Compiled by the Industry Research Division of Mizuho Bank, based on data from the European Commission's "Implementing The REPowerEU Action plan" and other sources.

Report summary

Demand for hydrogen in Japan (Mizuho's calculations)	• Japan's hydrogen demand in 2050 will be about 24 million tons/year (exceeding the approx. 20 million tons estimated in the Green Growth Strategy). • Hydrogen is expected to be used in power generation, automobiles, and steel, but the amount of hydrogen demand is not expected to be as much as estimated in the Green Growth Strategy. • Demand for hydrogen as an alternative to gas energy is expected to be large and second only to power generation. • Japan's hydrogen demand is assumed to be tail heavy, increasing rapidly from 2030 to 2050.
Hydrogen supply in Japan (Mizuho's calculations)	• Japan's hydrogen supply in 2050 is expected to be maximum around 4-5 million tons per year, and approximately 20 million tons per year of hydrogen imports will be needed. • By 2050, importing blue hydrogen and ammonia from the Middle East will be the most economically viable option; however, relying solely on specific countries or regions for hydrogen and ammonia imports poses energy policy risks. • Blue and green hydrogen from the US and Australia have considerable price competitiveness, and if suitable locations for CCS and transportation networks are secured, the cost competitiveness of domestic production will not be significantly inferior to imported hydrogen. Therefore, it is essential for Japan to consider a balanced hydrogen procurement approach.
Hydrogen strategies and hydrogen diplomacy of the countries・regions	• Europe's hydrogen demand for 2030 is set at 20 million tons per year, with a target of 10 million tons for both domestic production and imports. Governments and the private sector are promoting green hydrogen production in Europe, as well as in Africa, the Middle East, Central and South America, and Australia to establish a hydrogen hub, and reduce costs through scaling up. • South Korea is promoting large-scale commercialization at an early stage, backed by more than 4 trillion yen in private investments according to government policies. Countries such as Germany, France, the UK, and Australia have formulated and revised national hydrogen strategies, intensifying international competition in the hydrogen sector. • Japan's efforts are focused on R&D and demonstrations that contribute to the construction of a hydrogen supply chain. In recent years, policy support and demonstrations aimed at securing suitable overseas supply sites and domestic receiving bases.

How can Japan win the global competition for hydrogen?

Issues

- Japan's demand for hydrogen is small compared to Europe and other countries, and will take time to spread.
- Japan's hydrogen supply will be mainly imported from overseas.
- The speed and scale of plans for spreading hydrogen use in other countries far outstrip those in Japan.
- Japan and Japanese companies are ahead in hydrogen-related technologies and have the potential to show their technological superiority through ongoing R&D and demonstrations.

Source: Compiled by the Industry Research Division of Mizuho Bank.

Assumed scenario for spread of hydrogen demand

- Considering the low probability of introducing regulatory measures in Japan, early transition to hydrogen energy requires the establishment of technologies and cost competitiveness compared to existing energy sources.
- We have outlined some assumed scenarios for hydrogen use below. However, the key to early expansion lies in power generation, substitution for gas, and automobiles, where hydrogen demand is large, and the probability of hydrogen adoption is high.

Assumed scenarios for hydrogen use from 2030 to 2050

Power Generation	■ As of 2022, the cost of hydrogen-only combustion (52 JPY/kWh) and mixed combustion (20.9 JPY/kWh) is higher than that of gas-fired power generation (10.7 JPY/kWh). ■ By 2030, some gas and coal-fired power plants are expected to be co-fired with hydrogen/ammonia, and as of 2050 all become purely hydrogen/ammonia combustion or be equipped with CCS.
Gas Alternatives	■ As of 2022, synthetic methane (120 JPY/Nm3) is more expensive than LNG (40-50 JPY/Nm3), and practical usage will require further technological developments and the procurement of low-cost hydrogen. ■ By 2030, experimental, small-scale use of synthetic methane will be introduced, with large-scale use expected by 2050.
Automotive	■ As of 2022, the cost per km of diesel fuel and fuel hydrogen is almost equal (although FCEVs are significantly more expensive than internal combustion engine vehicles, and there is a possibility of a fuel tax being levied on hydrogen in the future). ■ With the commercialization of commercial FCEVs (trucks and buses), further expansion of hydrogen stations, reduction of vehicle prices due to FC module packaging, and reduction of fuel hydrogen prices are expected to drive the widespread adoption of commercial FCEVs after 2030.
Steel	■ If technological development proceeds according to the Ministry of Economy, Trade and Industry's technology roadmap, about 40% of crude steel production is expected to shift to hydrogen-reduced iron during the blast furnace improvement period after 2040.
Ships	■ The power sources for ships include electricity (batteries), hydrogen (fuel cells, fuel), ammonia (fuel), and carbon recycling methane (fuel), with multiple options will being developed in parallel. ■ Assuming technological development, infrastructure development, and cost reduction, hydrogen is expected to be used in small domestic vessels, while ammonia is expected to be used in large international shipping vessels.

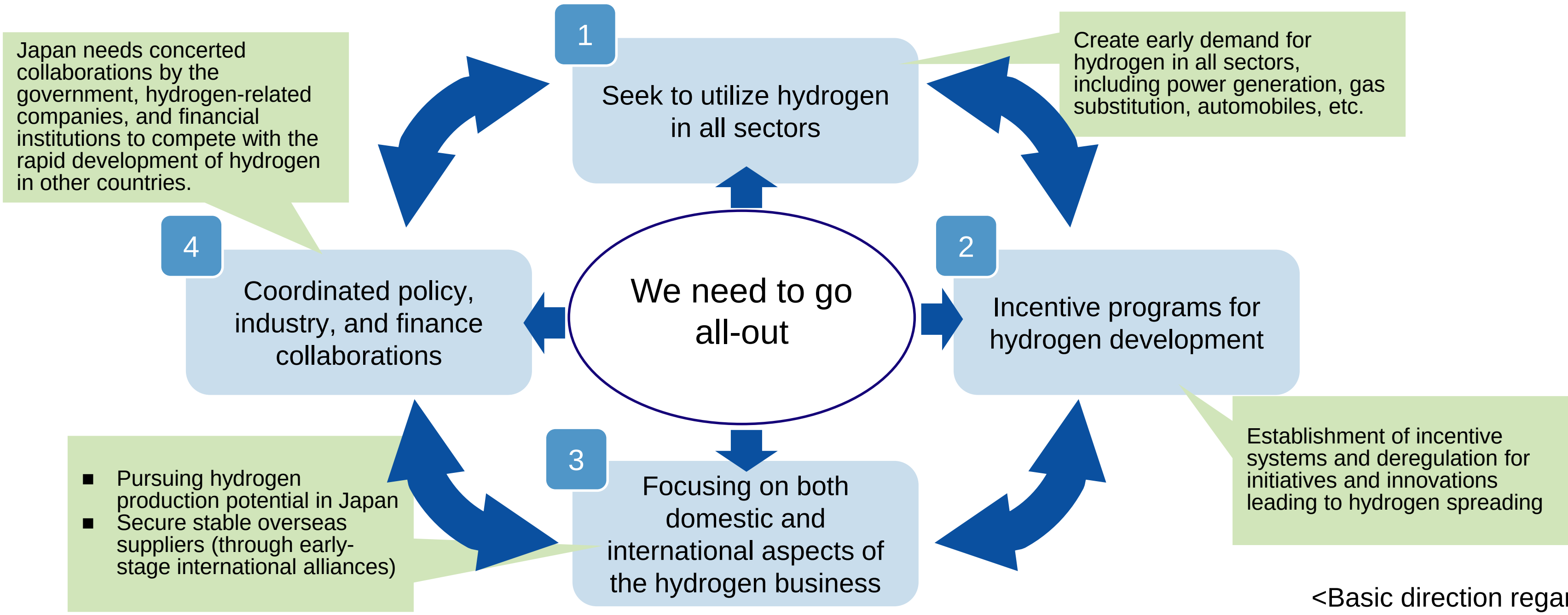
Power generation, gas substitution, and automobiles will be the key, as they have large hydrogen demand, a high probability of hydrogen development, and a relatively early spread of hydrogen usage.

Source: Compiled by the Industry Research Division of Mizuho Bank.

[Summary] Total commitment to the spread of hydrogen will lead to the realization of S+3E

- Japan must respond all-out if it is to compete with Europe and other countries in the global competition for hydrogen.

Winning the global hydrogen competition will require a virtuous cycle of policy, industry, and finance



The above initiatives will lead to improvement in the 3Es of energy security, economic efficiency, and environment.

- ✓ Promoting early development of hydrogen-related technologies and simultaneously expand demand and supply toward 2030.
- ✓ Enhancing resilience through the construction of a stand-alone hydrogen energy supply system tailored to local conditions.
- ✓ Improving energy self-sufficiency by increasing domestic hydrogen production potential, rather than just relying on imported hydrogen.
- ✓ Building international alliances to secure hydrogen interests is one idea. It is important not to reduce the ratio of independent development even after the transition to hydrogen.

<Basic direction regarding energy policies>

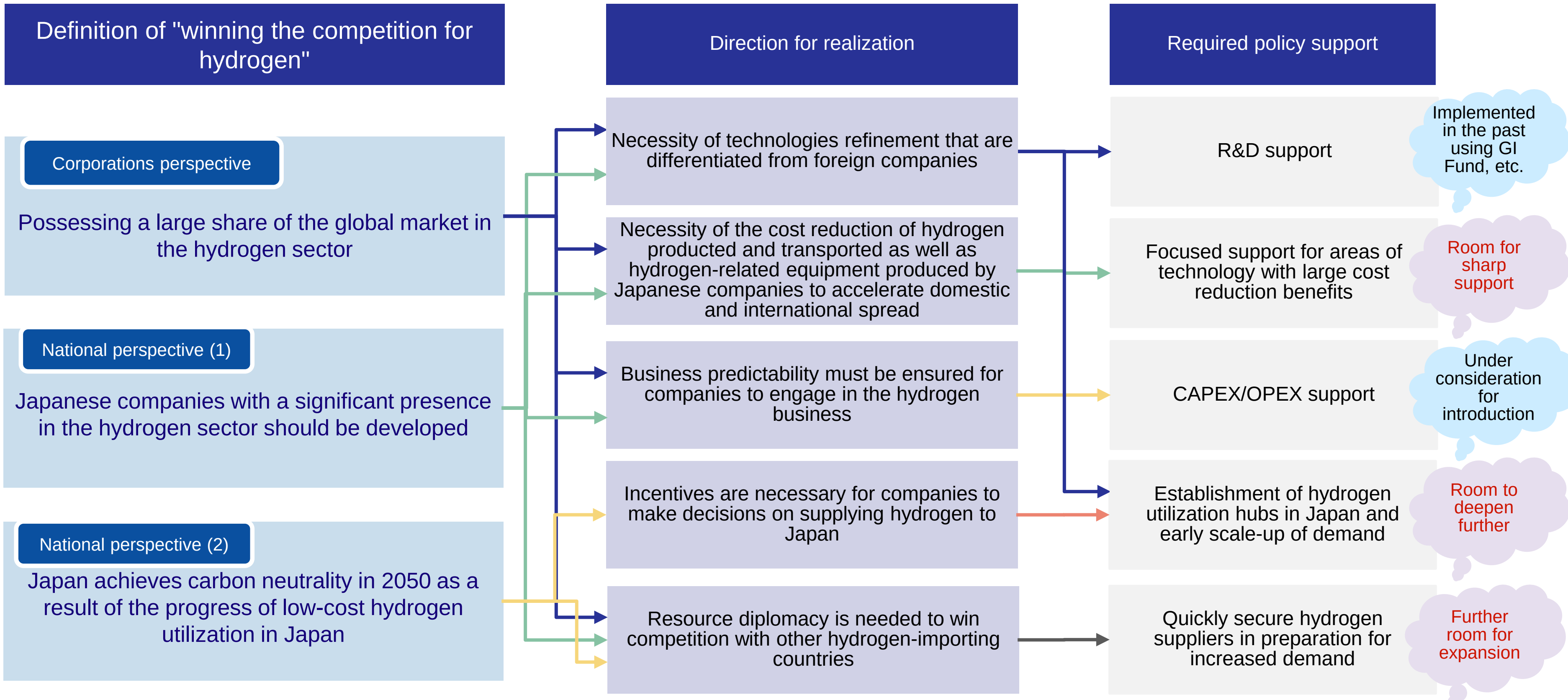
- Safety
- Energy Security
- Economic Efficiency
- Environment

Source: Compiled by the Industry Research Division of Mizuho Bank.

How Japan can win the competition for hydrogen

- To win the competition for hydrogen, Japanese companies which have strong presence in the hydrogen market are developed and affordable domestic hydrogen utilization is promoted to reach carbon neutrality by 2050.
- Various policies are being implemented and considered, but there is still room for additional, more in-depth support measures.

Definition and direction of winning

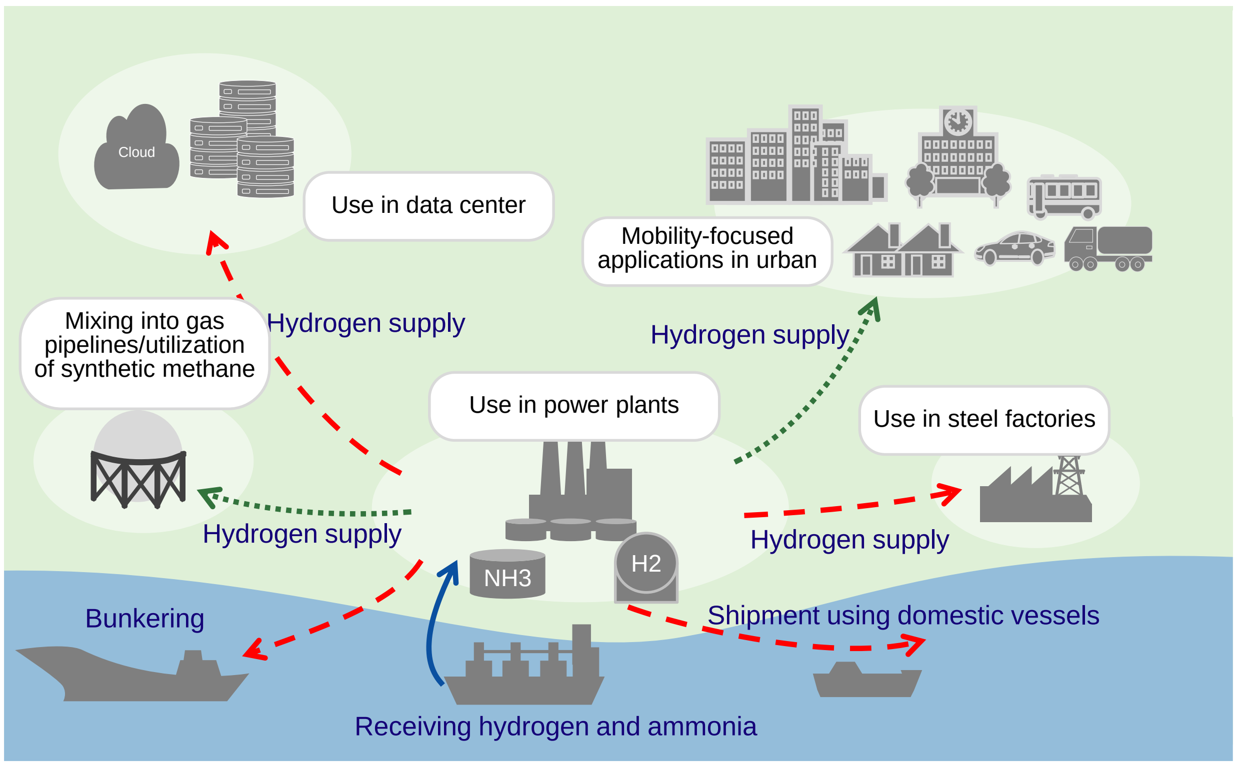


Source: Compiled by the Industry Research Division of Mizuho Bank.

Expected future policy: Quickly drive hydrogen demand through the formation of special coastal zones for hydrogen

- Designating specific areas as coastal hydrogen zones for imported hydrogen, beginning primarily with large-scale power plants, and providing public support as a national model project, is one valid option.
- In the future, a comprehensive design that envisions multifaceted hydrogen use, including mobility-focused utilization in urban , installation of bunkering hubs, and hydrogen-powered data centers, could also be effective.

Forming a concentrated special waterfront zone for hydrogen



- ✓ Public support for quay wall construction, cargo handling facilities, and installation of hydrogen and ammonia tanks as a national model project.
- ✓ First movers are encouraged and deregulated to induce rapid growth in demand for hydrogen and ammonia.
- ✓ In the long term, these zones are expected to serve as a hub for supplying hydrogen for steel factories, gas alternative, and commercial vehicles.

① First, it's assumed that hydrogen will be used for power generation, where demand for hydrogen is large, the probability of hydrogen is high (technology establishment will take place first), and hydrogen will spread relatively early.

② Expansion to other applications is assumed after that.

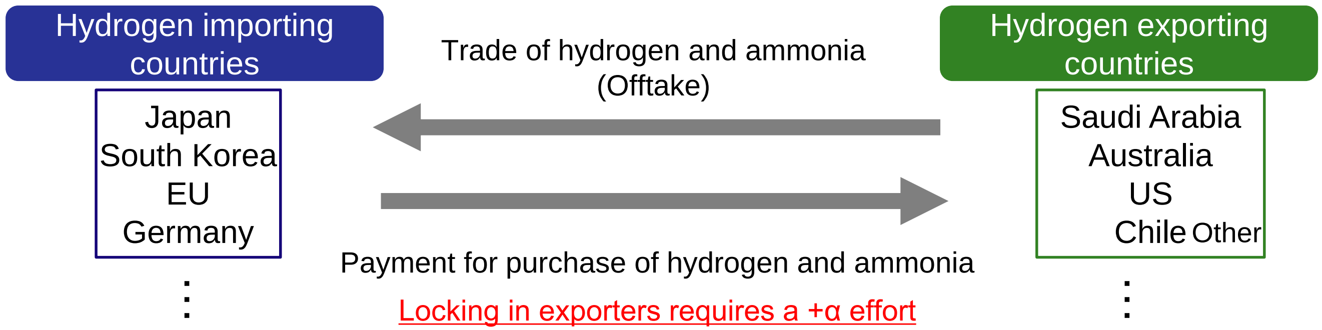
Short-term hydrogen flow (through 2030)
Medium-term hydrogen flow (2030s)
Long-term hydrogen flow (2040s)

Source: Compiled by the Industry Research Division of Mizuho Bank.

Expected future policies: early-stage securing of hydrogen procurement sources

- To realize the social implementation of hydrogen, it is essential to secure procurement sources as well as prompt demand as early as possible.
- Europe is aggressively approaching potential hydrogen exporting countries, and Japan must quickly secure suppliers to ensure it doesn't lose in the race for procurement.

Needs of hydrogen exporters and importers



Needs of hydrogen importing countries

- To secure enough hydrogen and ammonia to meet demand in country/region
- Stable and inexpensive procurement of hydrogen
- Green hydrogen and ammonia procurement preferred than blue
- Want to export their country's technological capabilities (to build a profitable system for their own country)

Needs of hydrogen exporting countries

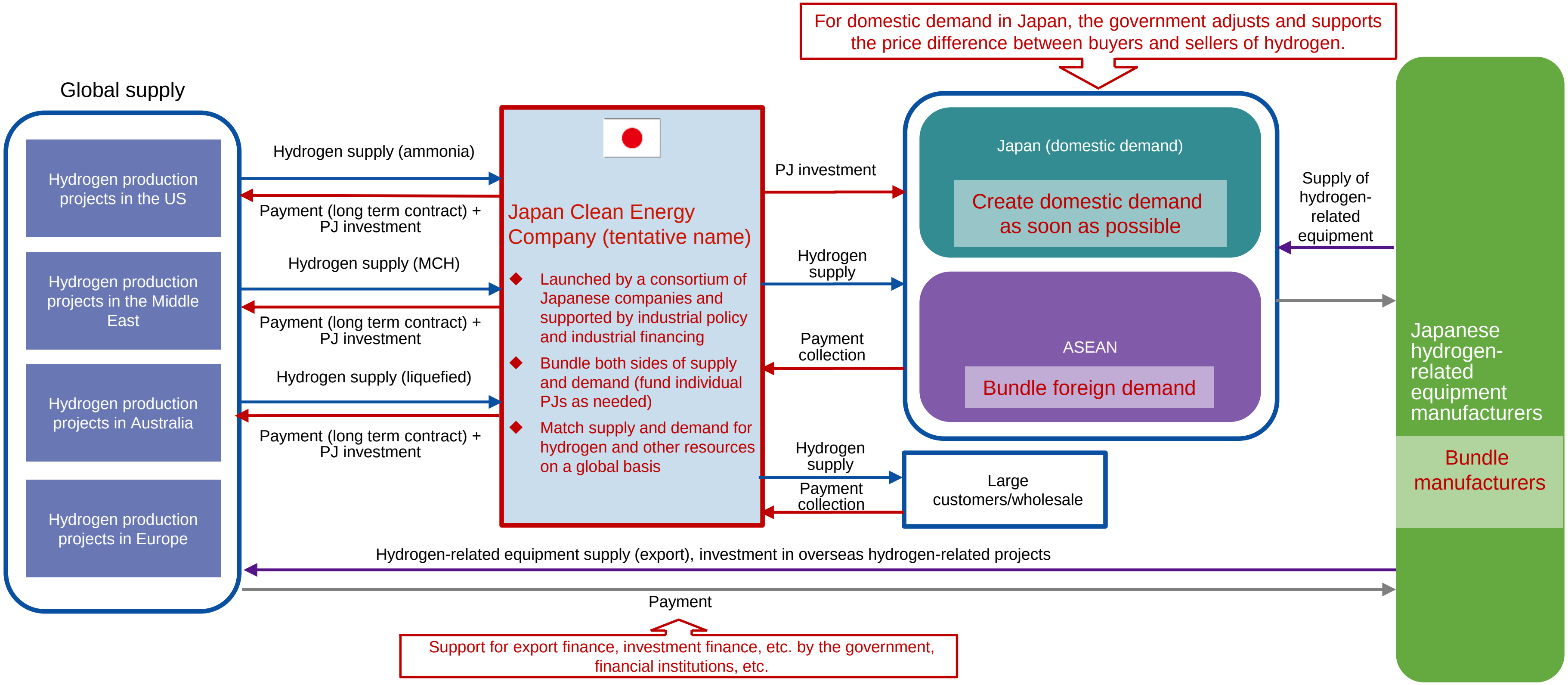
- Want to sell to countries that will buy large quantities at high prices
- Want to sell to countries with policy support and stable off-take
- Want to attract investment capital (to curb own spending)
- Want to take advantage of other countries' advanced technology
- Want to maintain higher export competitiveness than other countries
- Want the help of hydrogen use expansion in the own country

Source: Compiled by the Industry Research Division of Mizuho Bank.

Establishing a core company (flagship company) responsible for building a hydrogen supply chain is also an option

- To avoid scattered individual corporate efforts, forming a flagship company with a scale of trillions of yen from the outset as a consortium of Japanese companies could be an option.
  - a global clean energy company is created by bundling both supply and demand sides and matching them on a global basis, which can establish and capture market early
  - the missing pieces of underway hydrogen-related projects in overseas are off-takers and hydrogen-related technologies, therefore it is crucial to move early.

Business model of the core company responsible for building the hydrogen supply chain (image)



Source: Compiled by the Industry Research Division of Mizuho Bank.

Conclusion

- To compete with other countries in the hydrogen market, both steady hydrogen utilization and stable procurement are needed for Japan .
- A multifaceted approach both supply and demand is required.

Japan hydrogen reconstruction strategy

Japan's position

- ✓ World frontrunner in hydrogen in both public and private sectors
- ✓ Demand for hydrogen is expected to increase dramatically by 2050 to achieve decarbonization
- ✓ Potential for domestic hydrogen production is low

Intensified competition

Foreign countries

- ✓ Accelerated development of hydrogen technology
- ✓ Creation of hydrogen demand
- ✓ Secure hydrogen exporting countries

Demand-side support

- ✓ Promotion of hydrogen use in the power generation and gas sectors
- ✓ Reduction of hydrogen supply costs
- ✓ Development of domestic hydrogen utilization hubs

Supply-side support

- ✓ CAPEX/OPEX support for hydrogen suppliers
- ✓ Support for development of hydrogen-related technologies
- ✓ Satisfying the needs of exporting countries to secure hydrogen procurement sources

Steady use and stable procurement of hydrogen

Win the competition for hydrogen

Corporation perspective of

Possess a large share of the global market in the hydrogen sector

National perspective (1)

Japanese companies with a significant presence in the hydrogen sector are developed

National perspective (2)

Japan achieves carbon neutrality in 2050 as a result of the progress of low-cost hydrogen utilization

Source: Compiled by the Industry Research Division of Mizuho Bank.

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Link to a survey

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