Basic Hydrogen Strategy

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The Ministerial Council on Renewable Energy, Hydrogen and Related Issues

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Chapter 1 General

1-1. Background to the basic hydrogen strategy

In 2017, Japan formulated the world's first national hydrogen strategy, the Basic Hydrogen Strategy. Spurred by our move, a total of 26 countries and economies, including Japan, developed their hydrogen strategies by 2022.[1] In the following year, Japan hosted the Hydrogen Energy Ministerial Meeting (HEM), aiming to build momentum for top-down hydrogen policies, and has since played a leading role in the transition into a global hydrogen community.

Under this strategy, Japan achieved several accomplishments: the nation commercialized the world's first fuel cell vehicles (FCVs), increased the use of fuel cells by households, and achieved a world-class number of related patents. We have maintained our technological edge over the rest of the world and now lead globally. Built on the research and development achievements to date in the hydrogen-related sectors, including hydrogen transportation, hydrogen power generation, and use of hydrogen as heat sources in factories, we have also successfully demonstrated many different hydrogen-related technologies one after another.

Five years have already passed since the formulation of the Basic Hydrogen Strategy. Two epoch-making events have been experienced during the period. The first was the 2050 Carbon Neutrality Declaration, which was made in October 2020. Japan's sixth Strategic Energy Plan, which was revised in line with the pledge, envisions the power mix where hydrogen and ammonia will account for about 1% in FY 2030. The plan recharacterized hydrogen and ammonia as future energy fuel and carrier that also play a role in the power supply, rather than just new energy.

In addition, the 2-trillion-yen Green Innovation Fund (GI Fund), which was set up in conjunction with the Carbon Neutrality Declaration, allocated approximately 800 billion yen[2] to hydrogen-related technologies to finance technology development and demonstration efforts toward commercialization.

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[1] IEA *Global Hydrogen Review* 2022

[2] (1) Construction of large-scale hydrogen supply chains (budgetary limit: 300 billion yen) with the focus on developing and demonstrating technologies related to hydrogen production, transportation, storage, and power generation towards increased hydrogen supply capacity and reduced costs; (2) Hydrogen production through water electrolysis technologies, which utilize electricity produced from renewable energy (budgetary limit: 70 billion yen), with the focus on developing and demonstrating cost reducing technologies in a hydrogen-producing water electrolysis system; (3) Use of hydrogen in the ironmaking processes (upper limit: 193.5 billion yen) with the focus on developing and demonstrating technologies using hydrogen instead of coal to produce iron (ironmaking technology based on hydrogen reduction); (4) Construction of fuel ammonia supply chains (upper limit: 59.8 billion yen) with the focus on developing and demonstrating technologies for ammonia production and storage and power generation in the context of a large-scale ammonia supply chain construction and cost reduction; (5) Development of next-generation aircraft (upper limit: 21.1 billion yen) with the focus on developing elemental technologies including engines, fuel tanks, and fuel supply systems, which are required for hydrogen aircraft; (6) Development of next-generation vessels (up to 35 billion yen) with the focus on developing elemental technologies, including engines, fuel tanks, and fuel supply systems, which are required for hydrogen- and ammonia-fueled vessels; (7) Development of plastic raw material manufacturing technology using CO_2 (up to 33.5 billion yen out of the upper limit of 126.2 billion yen) with the focus on developing technologies for manufacturing plastic raw materials from CO_2 and waste plastic and rubber; and (8) Development of fuel production technologies using CO_2 and waste (up to 115.3 billion yen) with the focus on developing technologies recycling carbon dioxide into fuel as one of the options for transition into a decarbonized society.

The second event was the Russian invasion of Ukraine in February 2022. The event caused a tectonic disruption in the world's energy supply and demand structure, and at the G7 Elmau Summit, the leaders reaffirmed their intention to phase out their dependency on Russian-origin energy, which shed renewed light on the use of hydrogen as a realistic alternative. The EU and the UK have significantly raised their hydrogen production targets. Encouraged by the Inflation Reduction Act, the US stepped into the issue of unprecedented tax incentives and rapidly accelerated hydrogen production. The European Commission plans to start building a supply chain through huge budgetary measures allocated to hydrogen production and import projects under the Green Deal Industry Plan.

Japan aims to simultaneously achieve three goals: secure an energy supply, economic growth and enhanced international industrial competitiveness, and decarbonization through the Green Transformation (GX) initiatives. Under the growth-oriented carbon pricing vision, the government plans to contribute upfront investments worth 20 trillion yen in order to attract the public and private sectors to GX-related investments and achieve combined investments of 150 trillion yen or more over the next decade. The tasks of large-scale and resilient hydrogen and ammonia supply chains and support for supply infrastructure development will soon be placed on the agenda as urgent. In this context, our efforts to transition into a hydrogen-based society are moving from the technology development phase to the commercial phase. Whether a country can successfully move toward a hydrogen-based society may dictate whether it remains competitive. Therefore, the government should evaluate the achievements of hydrogen-related technologies regularly and more closely than ever before from the scientific viewpoints and appropriately allocate policy resources. It should also articulate the prospect for technology development and maximize investments from the private sector.

Earlier, the strategy was designed to build a domestic hydrogen market ahead of the rest of the world by establishing the hydrogen technology. However, given Japan's energy demand, the growth of the domestic hydrogen market is likely to be limited.[3] In contrast, the global hydrogen market is projected to yield annual revenues of $2.5 trillion and create 30 million jobs by 2050.[4] Given the expected galloping growth of the global market, the strategy should be revised in the direction of addressing the overseas markets.

The strategy should address the domestic and international market developments and put forward the roadmap for achieving carbon neutrality by 2050 as the shared vision of the public and private sectors. It should also state the awareness of challenges the country faces and its policy for addressing them, and express the country's ambition to accelerate the transition toward a hydrogen-based society. Note that in addition to the overarching hydrogen policy, the Basic Hydrogen Strategy will bring forward two key strategy components. One is the Hydrogen Industry Strategy. This component provides the policy for enhancing the competitiveness of Japanese industries in the hydrogen markets.

[3] The IEA's *World Energy Outlook* 2016 projects the percentage that Japan accounts for in global energy demand to decline to 2.3% by 2040 as compared with 5.1% in 2000.
[4] Hydrogen Council, IEA *World Energy Outlook* 2020 (Sustainable Development Scenario)

The other is the Hydrogen Safety Strategy, which aims to ensure that hydrogen is safely used. The strategy will be revised when appropriate but is normally reviewed every five years.

1-2. Scope of this strategy

Hydrogen is used as various fuels and raw materials. They include recycled carbon products: ammonia, e-methane, and synthetic fuel (e-fuel). The strategy will also address those materials and products. Their advantages, challenges, and development timelines should be closely examined. We will develop, demonstrate, and industrialize technologies for manufacturing and utilizing those products in a strategic manner to achieve carbon neutrality.

It should be noted that the “hydrogen” referred to in this series of terms, for example, the Basic Hydrogen Strategy and hydrogen-based society,[5] includes ammonia, e-methane, and synthetic fuels.

[5] "Hydrogen" referred to in the Hydrogen Industry Strategy, Hydrogen Safety Strategy, Hydrogen Policy, hydrogen industry, hydrogen demand, and effective use of hydrogen is intended to include ammonia and e-methane and fuels.

Chapter 2 Guiding principles for the use of hydrogen as an energy source

2-1. Principles for the widespread use of hydrogen in Japan

Hydrogen may be produced from various energy sources and is burned without emitting CO_2. It is the key energy source for carbon neutrality. In addition, hydrogen can be used not only as a fuel but also as a raw material. It shows great potential across many different industrial areas.

We hold the one-S and three-E philosophy for widespread use of hydrogen. *S* stands for safety and means the commitment to the development of effective safety technical standards, the prerequisite for a safe and secure hydrogen-based society. the three *E*s stand for energy security, economic efficiency, and the environment. Energy security implies that hydrogen has the potential for domestic production and diversified sources of supply and will contribute to greater resilient energy security. Economic efficiency means that the hydrogen industry has to achieve self-sustainability. The environment means the approach to prioritizing low-carbon hydrogen in order to achieve carbon neutrality. We will introduce hydrogen on the basis of the aforementioned S+3E. The specific direction to achieving the *S* (Safety) objectives are described in chapter 5, "Direction toward the safe use of hydrogen," and the specific milestones for the three-*E* (energy security, economic efficiency and environment) objectives are described in chapter 3 "Direction toward accelerating the transition to a hydrogen-based society."

The Ukrainian war and the global energy crisis prompted the United States and Europe to make huge investments, and the international competition for the hydrogen market is going to intensify. Japan has technological advantages in the hydrogen sector; therefore, it should encourage the Japanese hydrogen industries to enter the overseas markets and strengthen their international competitiveness. Chapter 4, "Directions toward strengthening the competitiveness of the hydrogen industry" addresses the industrial policy aspects of the hydrogen policy and describes specific directions.

(1) From the perspective of S+3E principle

A) Safety

Safety is a prerequisite for the transition into the future safe and secure hydrogen-based society. If you want to build a house or a society where hydrogen technologies are actively accepted, you have to lay the groundwork, which is safety. Hydrogen has unique properties; it is a light, colorless, and odorless gas that diffuses and leaks, embrittles metal materials, and readily ignites. We have to pay due attention to those characteristics and define an ideal hydrogen-based society from a global viewpoint. Built on the vision, we will lead international efforts to develop global standards for hydrogen technologies and develop effective safety standards.

B) Energy security

Russia's invasion of Ukraine has further increased uncertainty in the energy market, and in Europe, in particular, higher attention has been poured into the production and use of hydrogen as an alternative to natural gas production and energy utilization. For Japan, which lacks ready-to-use energy resources, the energy source is likely to contribute to energy security for several reasons. First, hydrogen may be produced from renewable energy sources and can, therefore, be produced and stored within Japan. The substance may be procured in other parts of Asia and Indo-Pacific countries. The sources of supply may be further diversified. In this sense, hydrogen also contributes to energy security.

In the context of energy security, we should also bring forth policy measures for reliably procuring and recycling rare metals and rare-earth minerals, which are essential for water electrolysis equipment and fuel cells, and developing innovative technologies for reducing rare metal consumption.

C) Economic efficiency

For the time being, fossil fuels, such as coal and petroleum, will be economically superior to hydrogen. Given the global move toward decarbonization, continued dependence on fossil fuels is controversial from the viewpoint of sustainability. The IEA's *Energy Technology Perspectives* 2020 projects the hydrogen produced through electrolysis (using electricity derived from renewable energy) to be cost competitive compared to existing fossil fuels as the costs related to renewable energy power sources continue to decrease. Furthermore, given the fluctuations in resource prices following Russia's invasion of Ukraine, hydrogen produced using renewable energy has had relatively slight price fluctuations. When carbon pricing programs gain momentum in Japan as well in the future, and when, as a result, the environmental value of carbon is converted into specific product prices, hydrogen as a non-fossil fuel will become a commercially self-sustaining fuel. It will probably provide an economically stable and attractive energy source option.

D) Environment

Hydrogen provides an alternative means for decarbonizing hard-to-abate sectors, including heat utilization for which electrification is difficult, and for replacement of carbon raw materials. Output from some renewable energy sources depends on the weather. If surplus renewable energy output is converted into hydrogen, the energy can be stored. Hydrogen may function as a balancing energy. Hydrogen and ammonia may not only be burned with or without fossil fuels to reduce or eliminate GHG emissions from thermal power generation but may also serve as a balancing energy and stability pathfinder, contributing to widespread use of renewable energy.

Hydrogen, therefore, is an energy that can contribute to the decarbonization for a wide range of industrial fields. In addition, we will prioritize low-carbon hydrogen production among many policy measures to increase the use of hydrogen in order to accelerate carbon neutrality.

(2) From the viewpoint of strengthening the international competitiveness of the Japanese hydrogen industry

Countries have been accelerating the growth of domestic industries in anticipation that demand for hydrogen will significantly increase. In Japan, fuel cell-related patents have been driving industrial competitiveness in the field of intellectual property. In order to maintain its technological advantage and to mobilize the momentum for accelerating the social implementation of hydrogen technologies, we should analyze global developments in all hydrogen-related markets and single out the markets where we should penetrate. We should also procure commensurate investments and grow the market. In the same vein, we should identify elemental technologies advantageous for Japanese industries and help companies enter the overseas markets with high hydrogen demand in order to strengthen international competitiveness.

2-2. Trends in hydrogen policy in some countries

Japan set forth the Basic Hydrogen Strategy in 2017, and since then, many countries have successively developed national hydrogen strategies. In addition, some countries set out plans to foster hydrogen industries. Shown below is an overview of policy trends in the countries.

(1) United States

In Hydrogen Shot,[6] which started in June 2021, the US made the commitment to reduce the clean hydrogen cost to $1 per kilogram in one decade. In the draft Clean Hydrogen Strategy and Roadmap (September 2022),[7] the US also made the commitment to increase clean hydrogen production from nearly zero today to 10 million metric tons per year by 2030, 20 million metric tons per year by 2040, and 50 million metric tons per year by 2050.

To achieve those goals, the Inflation Reduction Act (IRA, August 2022)[8] included about USD 369 billion (approximately 51.7 trillion yen) in the incentives for energy and climate-related programs and ten-year tax credits on clean hydrogen-related projects with producers receiving a maximum of $3.00 per kilogram of hydrogen. The Bipartisan Infrastructure Law (BIL, November 2021)[9] included ambitious upfront investment initiatives, including allocation of USD 9.5 billion (approximately ¥1.34 trillion) to clean hydrogen-related projects over five years. Of the planned

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[6] Department of Energy: Hydrogen Shot
[7] Department of Energy: National Clean Hydrogen Strategy and Roadmap
[8] Internal Revenue Service: Inflation Reduction Act
[9] Department of Energy: Bipartisan Infrastructure Law

investment, a maximum of $7 billion (approx. 980 billion yen) will be allocated to six to ten regional hydrogen hubs to address hydrogen feedstocks, end uses, and geographic diversity. [10]

(2) Europe

In the Hydrogen Strategy for a climate-neutral Europe (July 2020),[11] the EU set out objectives to install at least 6 GW of renewable hydrogen electrolyzers in the EU by 2024 and install at least 40 GW of renewable hydrogen electrolyzers by 2030. In addition, REPowerEU (March 2022) aims to end Europe’s dependence on Russian fossil fuels before 2030 and construct the capacity of 10 million metric tons per year of renewable hydrogen production in the EU and the same quantity of imports by 2030.[12]

To financially support the objectives, the European Commission approved and published the important projects of common European interest (IPCEI)[13] twice (in July and September 2022).

The first competition "Hy2Tech" held in July 2022 approved 41 Important Projects covering (1) hydrogen generation, (2) fuel cells, (3) storage, transportation and distribution of hydrogen, and (4) end-user (mainly in the mobility sector). These 41 projects will receive up to €5.4 billion in public funding, which is expected to unlock an additional €8.8 billion in private investments. The second competition "HyUSE" held in September 2022, HyUSE, approved a total of 35 projects in the areas of (1) infrastructure related with hydrogen and (2) industrial use of hydrogen. The projects will receive up to €5.2 billion in public funding, which is expected to unlock an additional €7 billion in private investments.

More recently, the European Commission published the Green Deal Industrial Plan (February 2023)[14] and established the EU Hydrogen Bank as one of its policy menus. The bank will launch a competitive tender in the autumn of 2023 to subsidize a fixed premium per kilogram of renewable energy-derived hydrogen produced over a 10-year period in order to sustain the production of renewable energy-derived hydrogen in the region. In addition, in conjunction with the revision of the Renewable Energy Directive, which is part of the European decarbonization policy package (Fit for 55)[15] announced in July 2021, the European Commission provisionally agreed on the objectives for implementation of hydrogen technologies, including the 42% share of green hydrogen in industrial hydrogen demand by 2030.[16]

(3) United Kingdom

[10] Office of Clean Energy: Regional Clean Hydrogen Hubs
[11] European Commission: A Hydrogen Strategy for a Climate-Neutral Europe
[12] European Commission: REPowerEU Plan
[13] European Commission: Important Projects of Common European Interest
[14] European Commission: A Green Deal Industrial Plan for the Net-Zero Age
[15] European Commission: Fit for 5': Delivering the EU's 2030 Climate Target on the way to climate neutrality
[16] European Commission: European Green Deal: EU agrees stronger legislation to accelerate the rollout of renewable energy

The British Energy Security Strategy (April 2022)[17] set forth an objective to increase hydrogen production to up to 10 GW by 2030 with at least half of this from electrolytic hydrogen.

In addition, the UK has a policy to increase production of low-carbon hydrogen in the 2020s through the Contract for Difference (CfD) schemes, including a low-carbon hydrogen business model, which compensates the price difference between low-carbon hydrogen and fossil fuels and the Net Zero Hydrogen Fund (NZHF) of up to 240 million pounds. The new energy security plan Powering Up Britain (March 2023)[18] indicates that these goals would be maintained and that the first round of the NZHF financial support for the electrolytic hydrogen project would be given.

(4) Germany

The National Hydrogen Strategy (June 2020)[19] includes the objectives of achieving 5 GW of hydrogen production capacity by 2030 and an additional 5 GW of hydrogen production capacity by 2035, if possible, or at the latest by 2040. More recently in November 2021, the coalition government agreement committed to achieving 10 GW of hydrogen production capacity by 2030.[20]

Germany kicked off the green hydrogen subsidy scheme "H2Global" that can purchase and sell hydrogen through tenders. It opened the first tender procedures to import green hydrogen in December 2022.[21] The tender process covered three green types of hydrogen derivatives: green ammonia, green methanol, and sustainable aviation fuel (SAF). The funding program is now considering hydrogen itself. Germany allocated 900 million euros for 2021 and 3.53 billion euros for 2023 as compensatory measures up to 2036.

(5) France

France's National Hydrogen Strategy (September 2020)[22] targeted 6.5 GW of electrolysis capacity by 2030. The program will receive 9 billion euros in funding by 2030.[23] The strategy targets decarbonized hydrogen, which includes not only hydrogen derived from renewable energy but also hydrogen derived from nuclear power. In October 2021, the French government set up the new investment plan France 2030[24] in order to enhance industrial competitiveness and create future industries. It aims to become a world leader in hydrogen production by driving research and development of green hydrogen technologies, including water electrolyzers.

[17] HM Government: British energy security strategy
[18] HM Government: Powering up Britain
[19] Federal Ministry for Economic Affairs and Energy: The National Hydrogen Strategy
[20] Sozialdemokratischen Partei Deutschlands (SPD), Bündnis 90 / Die Grünen Und Den Freien Demokraten (FDP): Coalition Agreement 2021–2025
[21] BMWK: Federal Ministry for Economic Affairs and Climate Action launches first auction procedure for H2Global - €900 million for the purchase of green hydrogen derivatives
[22] French Ministry for an Ecological and Solidary Transition, Ministry of Economy and Finance: Stratégie nationale pour le développement de l'hydrogène décarboné en France
[23] French government: Accélérer le déploiement de l'hydrogène, clé de voûte de la décarbonation de l'industrie
[24] French Presidency: France 2030 Décarbonation de l'industrie

(6) China

China set forth a medium- and long-term plan for development of hydrogen energy industry (March 2022),[25] which committed to achieving 50,000 FCVs by 2025, production of 100,000 to 200,000 tons of renewable energy-derived hydrogen per year, and 1 to 2 million tons of CO_2 emissions reduction per year. In September 2020, five ministries and commissions, including the Ministry of Finance, announced a subsidy funding program. To support FCV development, the program includes a policy for subsidizing FCV demonstration model city clusters as a function of the development of supply chains for vehicles and key components. It plans to annually provide subsidies of up to 1.7 billion yuan (approximately 34 billion yen) according to the specified requirements by 2025.[26] Many local governments have also set forth their own hydrogen industry development plans. For example, in September 2020 the Beijing City authorities announced the Beijing City Hydrogen Fuel Cell Vehicle Industry Development Plan,[27] which plans to increase the number of hydrogen vehicles operating on its streets to 10,000 FCVs and the number of hydrogen filling stations to 74 by 2025. In October 2022, Jilin Province authorities put forth the Hydrogen Energy Promotes Jilin Action Plan.[28] The plan set a goal of producing 60,000 to 80,000 tons/year of green hydrogen by 2025 (250,000 to 350,000 tons/year of ammonia and other materials) and 300,000 to 400,000 tons/year of green hydrogen (2 million tons/year for ammonia and other materials) in 2030.

(7) South Korea

In the Roadmap for Revitalizing the Hydrogen Economy (January 2019),[29] the Korean government set the objective of achieving 5.26 million tons/year of hydrogen supply at the cost of KRW 3,000 (approximately 284 yen)/kg, respectively, in 2040. In the Vision for Becoming a Leading Hydrogen Economy Nation (October 2021),[30] the government set forth the pledge of producing 1 million tons of clean hydrogen by 2030 (250,000 tons of green hydrogen and 750,000 tons of blue hydrogen) and 500 million tons of clean hydrogen (3 million tons of green hydrogen and 2 million tons of blue hydrogen) by 2050. In addition, in February 2021, the Ministry of Trade, Industry and Energy released the Hydrogen Economy Promotion and Hydrogen Safety Management Act (Hydrogen Act).[31] The Hydrogen Act includes the certification, development, and support for hydrogen-specialized enterprises, safety management of fuel cells, water electrolyzers, and facilities that use hydrogen, along with requests for the installation of hydrogen stations and fuel cells.

25 中国・国家発展改革委員会「氢能产业发展中长期规划(2021-2035 年)」
26 財政部等「开展燃料电池汽车示范应用的通知」
27 北京市「北京市氢燃料电池汽车产业发展规划(2020-2025 年)」
28 吉林省「“氢动吉林”行动」
29 韓国政府「수소경제 활성화 로드맵」
30 産業通商資源部「수소경제 성과 및 수소선도국가 비전」
31 産業通商資源部「수소경제 육F성 및 수소 안전관리에 관한 법률」

(8) India

Under the National Hydrogen Green Mission (January 2023),[32] the Indian government set up the Strategic Intervention for Green Hydrogen Transition (SIGHT) program, which will allocate funds of 174.9 billion rupees to provide different financial incentives for domestically manufacturing water electrolyzers and green hydrogen production. The program plans to allocate INR 14.66 billion to hydrogen-related demonstration projects, INR 4 billion to research and development, and INR 3.88 billion to others. The program states that the equipment needed for water electrolysis and green hydrogen production requires government approval and suggests the possibility of announcing a list of approved models and manufacturers.

(9) Singapore

In the National Hydrogen Strategy (October 2022),[33] the government predicts that hydrogen power generation will be capable of meeting up to 50% of the domestic electricity demand by 2050. It plans to increase the use of low-carbon hydrogen and the construction of infrastructures in pace with the technology developments achieved and global developments. As a national research and development project, the Low-Carbon Energy Research (LCER) Funding Initiative includes funding of 55 million Singapore dollars (approximately 5.5 billion yen) for the first phase of research, and an additional 129 million Singapore dollars (approximately 12.9 billion yen) for the second phase. In addition, it lists prioritized policy areas, including the development of finance ecosystems, development of a certification scheme for hydrogen origin, it focuses on support for research cooperation, etc., and seeks mutual benefits from international partnerships.

(10) Australia

Since the release of the National Hydrogen Strategy (November 2019),[34] the country has focused on fostering the hydrogen industry. It set an objective of being a global leader in hydrogen production by 2030. Specifically, it plans to support green hydrogen projects to achieve a maximum of 1 GW of water electrolyzer capacity by 2030.[35] In addition, it envisages international cooperation to establish a certification scheme for the origin of clean hydrogen. It has already started to develop a specific design for the certification scheme and draft the relevant legislative framework in order to support internationally consistent clean hydrogen trading.[36]

(11) Chile

[32] Ministry of New and Renewable Energy: National Green Hydrogen Mission
[33] Ministry of Trade and Industry Singapore: Singapore's National Hydrogen Strategy
[34] COAG Energy Council Hydrogen Working Group: Australia's National Hydrogen Strategy
[35] Department of Climate Change, Energy, the Environment and Water: Hydrogen Headstart Program
[36] Department of Climate Change, Energy, the Environment and Water: Guarantee of Origin Scheme

The National Green Hydrogen Strategy (November 2020)[37] plans to produce the cheapest green hydrogen by 2030 in order to achieve carbon neutrality by 2050. It estimates that Chile has over 1,800 GW of renewable energy potential and plans to invest $5 billion to build 200,000 tons/year of green hydrogen production capacity by 2025.

[37] Ministry of Energy: National Green Hydrogen Strategy

Chapter 3 Direction toward accelerating the transition to a hydrogen-based society

3-1. Supply of stable, inexpensive, and low-carbon hydrogen and ammonia

(1) Stable supply (Energy Security)

In order to supply inexpensive hydrogen and ammonia in large quantities stably and over the long term, it is critically important to create the demand that hydrogen may meet. Given the need for that demand, we should not only establish a base for producing hydrogen from domestic resources but also increase the use of hydrogen produced overseas. Countries and economies have different underlying conditions, including the potential capacity of renewable energy production and market size. Currently, however, Japan has the objective of using up to 3 million tons/year by 2030 and approximately 20 million tons/year by 2050 in order to accelerate the transition toward a hydrogen/ammonia-based society. We will set an additional objective of using 12 million tons of hydrogen (including ammonia) per year for 2040. We will revise the targets against the prospect of potential hydrogen demand. In addition, in order to accurately determine the use of hydrogen, we will develop a statistical collection system for quantitative data on hydrogen production and consumption.

(2) Reduction of supply cost (Economic Efficiency)

The supply of inexpensive hydrogen and ammonia is a prerequisite for increasing the utilization of hydrogen. Our hydrogen supply cost (CIF cost) targets are 30 yen/Nm^3 (approximately 334 yen/kg) in 2030 and 20 yen/Nm^3 (approximately 222 yen/kg, a value set to reduce hydrogen power generation costs below gas-fired power generation costs) by 2050. The ammonia supply cost (CIF cost) target for 2030 was set at the upper 10-yen level/Nm^3 (hydrogen equivalent in calorific value). In recent years, fossil fuel prices have fluctuated greatly. The LNG price as of March 2023 is equivalent to 24 yen/Nm^3 of hydrogen. The hydrogen supply cost target, therefore, is identical to the recent fossil fuel price. We will continue to support technology development with the Green Innovation Fund to achieve the supply cost target. Furthermore, we will fully mobilize a variety of measures under the strategy to stimulate the demand for hydrogen and ammonia and give incentives to the private sector to increase investment. Combined with further technological innovation, those measures will achieve the additional supply cost reduction targets set forth from the perspective of international competitiveness.

Given the instability in fossil fuel prices, as demonstrated by fuel prices that soared in response to the Russian invasion of Ukraine, we should build a supply chain resilient to fossil fuel price fluctuations because fuel hydrogen and ammonia may prevent and mitigate the effect of sudden price increases.[38] Although constraints, including technology levels and economic feasibility, and market

[38] The Summary of the Green Growth Strategy (June 18, 2021) (pp. 45 and 49) estimated that both hydrogen and ammonia would reduce household electricity charge by approximately 8,600 yen/year.

risks cannot be neglected for the time being, we will monitor technological and international market developments and review the appropriate target price toward 2050. We will also construct new or revised schemes as needed.

(3) Transition to low-carbon hydrogen (Environment)

Generally, hydrogen may be produced from a variety of raw materials using different processes, including natural gas and lignite reformation, water electrolysis using electricity produced from renewable energy sources or fossil fuels, and a combination of these processes with CCUS/Carbon Recycling technologies. In order to ensure that hydrogen and ammonia help to steadily achieve carbon neutrality, we have to set carbon intensity targets for hydrogen and ammonia.

In April 2023, Japan hosted the G7 Ministers' Meeting on Climate, Energy, and the Environment in Sapporo. The Ministerial Statement stated that hydrogen and ammonia will contribute to decarbonization in various fields and industries and that they especially contribute to zero-emission thermal power generation in the electric power sector. In addition, the statement referred to an IEA report, "Towards hydrogen definitions based on their emissions intensity," which brought forth the importance of building a supply chain based on carbon intensity. Carbon intensity characterizes hydrogen in terms of CO_2 emissions rather than color codes, including blue or green. The statement said that the countries recognized the importance of establishing international standards and certification schemes for carbon intensity-based trading and welcomed the IEA report. Later, the G7 Hiroshima Summit also recognized the importance of establishing international standards and certification schemes for carbon intensity-based trading. The International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) proposed a calculation methodology for carbon intensity, which may be accepted as the international standard. The Japanese government will set the low carbon targets in no way inferior to other countries according to the calculation methodology and push forward the widespread use of hydrogen in line with the targets. Specifically, the more demanding target for carbon intensity was set at 3.4 kg-CO_2 or less of carbon emissions from 1 kg of hydrogen production at the well to the production gate.[39] The target is not believed to be technically unachievable in light of the current technology level. The hydrogen that meets the target carbon intensity is qualified as low-carbon hydrogen. Similarly, the ammonia that is produced from hydrogen with emissions of 0.84 kg-CO_2e/kg-NH_3 or less per 1 kg gate to gate (including hydrogen production) is qualified as low-carbon ammonia. Note that although the target carbon intensity calculation respects consistency with international standards, the calculation coverage is also determined by taking into account the geographical conditions of Japan, transportation length that may be significant for hydrogen produced overseas, conversion to carriers, and the CO_2 emitted from the hydrogen separation and recovery process. We will contribute to solving global environmental issues by minimizing emissions in the Life Cycle Assessment (LCA).

[39] From raw material production to the outlet of hydrogen production equipment

However, the definition of low-carbon hydrogen described here will be revised as necessary in light of future technological progress.

3-2. Efforts on the supply side

The specific directions leading to achieving the objectives mentioned above are described below from the perspectives of supply and demand, institutional development, cooperation with local governments, innovative technology development, and international cooperation.

(1) Construct hydrogen supply chains in Japan

A) Establish production bases for domestic hydrogen production

From the perspective of strengthening energy security, it is important to build domestic hydrogen production and supply systems. On the other hand, some observers believe that the hydrogen produced in Japan will remain more expensive than the hydrogen imported from overseas for the time being due to the higher cost of renewable energy production and CCS in Japan. However, the price of surplus electricity is reduced when renewable energy output is controllable. Hydrogen is expected to play a role in balancing energy and to contribute to penetrating renewable energy into the market. Given those factors, we should push forward the use of hydrogen in a manner that fully utilizes the opportunities to produce hydrogen domestically. For that purpose, when we want to close the price gap between hydrogen fuel and conventional fuels, with a view to strengthening energy security, we should selectively maximize the support to domestic businesses that are likely to achieve sufficient price reductions and competitiveness in the future.

In the field of hydrogen production, the demand for water electrolyzers is expected to continue growing because the equipment has the industrial advantage of producing hydrogen from renewable energy. The world will have 134 GW of installed electrolyzer capacity by 2030.[40] If Japanese companies enter this segment of the hydrogen market, which is also an upstream segment of the hydrogen supply chain, either in Japan or overseas, Japan will increase its presence in the energy supply market around the world.

To this end, we will set a new water electrolyzer capacity target of around 15 GW in combined domestic and international markets for Japanese-related companies (including parts and materials manufacturers) by 2030 to strengthen the grounds for hydrogen production. The said introduction targets will be reviewed in a timely and appropriate manner in accordance with future trends in technological development and the spread of global demand.

B) Develop regulatory incentives for increasing use of low-carbon hydrogen

[40] IEA *Global Hydrogen Review* 2022

The price of renewable energy is rather expensive, and the CCUS/Carbon Recycling cost also remains at a higher level. Because of these cost factors, the production cost of low-carbon hydrogen remains higher. Therefore, it is necessary to create an environment where the demand side finds a fair value for low-carbon hydrogen and where low-carbon hydrogen is traded at a fair price.

We aim to increase the share of low-carbon hydrogen in the overall hydrogen and ammonia supply in Japan from the very early stage of the efforts toward the widespread use of hydrogen and ammonia. To successfully implement the policy, we have to develop transitional measures that incentivize the demand side to willingly bear the certain cost burden. Specifically, we have to (1) develop a market design that provides incentives for purchasing low-carbon hydrogen and (2) establish regulatory incentives for more low-carbon hydrogen supply.

C) Develop enabling conditions for hydrogen production combined with CCUS and Carbon Recycling

In producing low-carbon hydrogen, CCUS/Carbon Recycling initiatives are essential, such as CCU/Carbon Recycling for capturing and reusing the CO2 generated during hydrogen production by reforming natural gas and lignite, water electrolysis using fossil fuel-derived electricity, etc., and CCS for underground storage.

As for CCU and Carbon Recycling, we will use the GI Fund to support the establishment of Carbon Recycling technology, which effectively uses CO_2 as a raw material, and its social implementation.

As for CCS, the government will accelerate the development of the business environment, including the establishment of related business laws and will provide a clear outlook of having an annual storage capacity of 6 to 12 million tons by 2030 in order to launch the CCS business by 2030.

(2) Build an international hydrogen supply chain

A) Strengthen relationship with potential suppliers

Since hydrogen, ammonia, e-methane, and synthetic fuel (e-fuel) can be produced from renewable energy sources and transported across the sea as well as fossil fuels, those materials would help diversify the energy suppliers and contribute to further enhanced energy security. EU members and other countries have stepped into competition for upstream interests, which should be more precisely named overseas hydrogen resource interests and are planning large-scale upstream investments. Even non-oil producing countries may be hydrogen producers using water electrolyzers if they are rich in renewable energy. As fuel, hydrogen is relatively free from uneven regional distribution than conventional fuels; therefore, we have to build relationships with many countries. Japan has extensive energy resource diplomacy experience with resource-producing countries. Built upon the cooperative relationships, the government will need strong leadership to increase partnerships with hydrogen and ammonia producing countries, including emergent resource-rich countries, through memorandums of cooperation and multilateral frameworks. It will also accelerate the implementation of the plan for constructing international supply chains and establishing their logistic hubs in collaboration with North America, the Middle East, Australia, and Asia.

Note that in the context of international supply chain construction efforts, we will strive to increase the involvement of Japanese companies in upstream interests. We will aggressively engage Japanese companies in hydrogen production and transportation and plant construction in the countries involved in order to ensure a stable supply to Japan. We will also try to ensure that products related to Japanese companies are extensively used at the overseas hydrogen production sites. We aim to enhance energy security in a manner to complement the industrial promotion policy for Japanese companies. The approach will create a virtuous cycle that promotes mutually beneficial relationships between hydrogen suppliers and Japan as a hydrogen demanding country and leverages the same relationships to contribute to a sustainable supply chain and a future hydrogen-based society.

B) Address the risks related with supply chain construction (funding)

Hydrogen transport and conversion technologies have not yet fully developed. The outlook for hydrogen price declines and for demand remains uncertain. Establishing an early hydrogen supply chain is a risky undertaking at present. As long as technologies are not established in the production, transportation, and storage sectors, delays may occur anywhere from upstream to downstream in the supply chain infrastructure, and the supply chain is always at risk of disruption. The government will create a nongovernmental insurance mechanism to cover those risks. If the risks are significant, public institutions will partly shoulder the risks to create enabling business conditions and increase investments by business operators and funding by financial institutions.

3-3. Efforts on the demand side

(1) Create demands

Hydrogen may make versatile contributions; it decarbonizes heat use in the sectors that are difficult to electrify, eliminates GHS emissions in the power supply sectors, decarbonizes the transport and industrial sectors, produces carbon-recycled products of synthetic fuel (e-fuel) and e-methane, and increases efficient use of renewable energy. Its importance is further expected to increase in the future.

Specifically, we will elaborate and implement the strategies for creating demand in the power generation, fuel cell, and heat and raw material utilization sectors in light of domestic and international developments in order to enhance the industrial competitiveness of Japanese companies in these sectors and for hydrogen demand itself.

A) Power generation sector

The use of hydrogen and ammonia in the power generation sector is expected to ensure the stable supply of energy and at the same time to reduce CO_2 emissions from thermal power generation. They are promising materials in supporting the transition toward carbon neutrality and a decarbonized society. A large amount of demand for hydrogen is projected. The sixth Strategic Energy Plan, therefore, set the target percentage of hydrogen and ammonia in the power mix for FY 2030 at approximately 1%. Indeed, hydrogen and ammonia are positioned as driving forces for increasing demand and reducing supply costs toward a large-scale first supply chain in 2030. In addition, we should implement incentive measures to increase the use of hydrogen and ammonia as fuel for in-house power generation in order to accelerate carbon neutrality.

In the hydrogen power generation sector, co-firing and mono-firing combustors have been developed for small gas turbines, and they have been demonstrated in actual equipment toward the 2030 carbon neutrality goals. As for large gas turbines, Japanese companies have worked to develop 30% co-firing and mono-firing combustors. They should focus on developing 30% or more co-firing and mono-firing combustors that conforms to overseas gas-fired power standards, such as the EU taxonomy, and demonstrating them on actual gas turbines.

As for ammonia power generation, a demonstration project for ammonia co-firing at coal-fired power plants started in FY 2021. The plants aim to conduct a 20% co-firing test on a 1,000 MW actual unit in commercial service in FY 2023 and start commercial operation in the latter half of the 20s. Efforts to achieve a co-firing ratio of over 50% and develop a mono-firing burner are also ongoing under the auspices of the GI fund. Mono-firing technology has been established for small, 2 MW-class gas turbines. The technology was shown to be capable of generating power at more than 99% less greenhouse gas emissions during combustion. We will develop the plan to construct large-scale plants.

In order to create demand, we will achieve a wide range of co-firing ratios beyond the existing ratios, including mono-firing for hydrogen and ammonia power generation in the latter half of the 2020s up to 2030 and offer a wide range of options in line with the move toward decarbonization on the consumer side. We will support upcoming combustor development projects with the GI fund to accelerate demonstrations in actual equipment and subsequent social implementation. In principle, we will replace conventional thermal power generation with decarbonized thermal power, which uses hydrogen, ammonia, and other decarbonized fuels or CCUS/Carbon Recycling technology, toward 2050. The Act on Sophisticated Methods of Energy Supply Structures[41] requires that electricity retailers procure non-fossil power sources by 44% or more of the electricity they sell in FY2030. In addition to the regulatory measures, support measures are also planned, including a long-term decarbonized power supply auction scheme, which is scheduled to launch in FY 2030. The government plans to promote the use of hydrogen and ammonia in the power generation sector through combined regulatory and support measures. It plans to shift from co-firing to mono-firing technologies to decarbonize thermal power generation toward carbon neutrality by 2050. It will also enter into partnerships with the regions with potential demand for hydrogen and ammonia.

B) Fuel cell sector (mobility and power generation)

Japan is the leading country in the world in fuel cell technologies, and Japanese companies have the most patents awarded in the sector. The fuel cells are widely used as mobile power sources in various sectors, including automobiles, railways, port cargo handling equipment, and power generation. They are also used in stationary equipment in residential spaces, offices, and factories. In addition, given that water electrolyzers, whose mechanism is the reverse of the fuel cell reaction, have recently been developed, fuel cells are critically important for the hydrogen industry as a whole, in other words, not only in the demand sector but also in the supply sector.

Above, demand growth measures have been considered for each individual use. As long as our focus is restricted on segmented markets, however, we will not open the path toward commercialization and independence of the fuel cell technologies. Japan has technological strengths in the area of fuel cells, and the technology will be needed in any application. Rather, we should look at it as an integrated market beyond industrial segments and/or national boundaries and create a business landscape where Japanese fuel cells are installed in all equipment in order to establish itself as a platformer in the promising market.

Specifically, we will first increase the industrial feasibility of the fuel cell business through comprehensive support, including the Strategic Basic Technology Upgrading Support Project. We will win overseas outstanding demand ahead of the rest of the world and achieve mass production and cost reductions. At the same time, we will see the growing demand for fuel cells in Japan as the mother market, which can be a key for industrialization, because it stimulates the further demand in a cross-sectoral manner. For example, in the automotive sector, we will put higher priority on commercial vehicles, which may more effectively utilize the benefits of FCVs, in addition to conventional passenger cars. We will encourage Japanese automobile manufacturers, station operators, logistics operators, and consignors to share the same roadmaps. They will drive strategically important business projects and increase the use of cell fuels within the country. In the consumer product sector, we will boost the use of

[41] The Act on the Promotion of Use of Non-fossil Energy Sources and Effective Use of Fossil Energy Materials by Energy Suppliers (Act No. 72 of 2009)

household fuel cells to increase the demand. We will also support technology development and equipment upgrade. Our efforts will be also directed toward improving power generation efficiency of commercial and industrial fuel cells.

C) Heat and raw material utilization sectors

(i) Use hydrogen and ammonia as fuels (heat demand)

Energy consumption in the industrial sector accounts for 40% of the total final domestic energy consumption. The use for heat, which is among the typical hard-to-abate sectors, accounts for 75% of the energy consumption in the industrial sector. Given that the use of hydrogen and ammonia will prevail in the medium- and high-temperature segments of heat demand over the mid to long term, we will develop and demonstrate hydrogen and ammonia burner and boiler technologies in a manner to reflect the differences in temperatures required and processes among the industries. We will also increase the installation and use of hydrogen gas turbine co-generation systems in geographic areas where a certain amount of hydrogen is expected to be available and likely to effectively meet local thermal needs. The decarbonization of inland factories, for which access to a large-scale hydrogen supply chain is difficult, may be effectively achieved using on-site water electrolysis systems to produce hydrogen for use as a heat source. We will encourage those factories to install and use water electrolyzers, boilers, and other demand equipment.

(ii) Use hydrogen as a raw material (steelmaking industry)

The steel industry envisions the conversion of the production system from blast furnaces to electric furnaces as an immediate solution to carbon neutrality by 2050. However, you cannot meet the growing global demand for steel simply by using iron scrap in electric arc furnaces for ironmaking. Therefore, we have to also push forward development of hydrogen reduction steelmaking technology, which replaces coal with hydrogen as reducing agent for iron ore to produce steel. However, since the reduction reaction involved in the hydrogen reduction steelmaking process is an endothermic reaction, it is extremely difficult to industrialize the process for high productivity. The reaction requires a continuous heat supply to continue to melt iron ore and extract iron. Several large-scale projects for direct hydrogen reduction technology have been started in other countries. The efforts to use the technology in the real world have been accelerated toward social implementation. At present, countries around the world work to develop the technology toward social implementation. We have to closely monitor international developments and develop plans to increase the assistance.

Specifically, in Japan, the technology that is capable of reducing CO_2 emissions by 10% by injecting hydrogen (mainly by-product gas generated in-house) into a blast furnace has already been tested in a test furnace of 1/400 scale (COURSE50 project), and the expected reduction was demonstrated. Now a demonstration project on a large-scale blast furnace for hydrogen reduction ironmaking (COURSE50) is underway with the support of the GI Fund and other funding facilities toward commercialization of the technology by 2030. In addition, the project also focuses on the technologies that would reduce CO_2 emissions by 50% by increasing hydrogen injection into the blast furnace (super COURSE50 furnace and Carbon-Recycling blast furnace) and the technologies that directly reduce solid iron ore with hydrogen without using a blast furnace (direct hydrogen reduction technology). Its research and development activities target social implementation by the 2040s. We have to closely monitor international developments and develop plans to increase the assistance for the technologies.

As for the direct reduction ironmaking process, if you construct a new direct reduction furnace, you should preferably construct it in a geographical area where a stable and unexpensive hydrogen supply is available. These kinds of furnaces are likely to be more cost-competitive when they are installed overseas than in Japan. Furthermore, when hydrogen is used in Japan, those furnaces will inevitably face a significant cost increase compared to the conventional reduction process. The Japanese steel industry, which directly or indirectly exports approximately 60% of its production, may lose its international competitiveness.

As discussed so far, the Japanese steelmaking industry anticipates a gradual increase in hydrogen demand in the latter half of the 2020s and later. Full-fledged hydrogen utilization will start in the 2030s, and the scale will depend on the progress in technology development and international competition over the upcoming ten years. For the decision-making factor for companies' domestic investment over production process conversion in the steel industry, it is extremely important to consider whether or not the necessary amount of hydrogen will be supplied stably and at low cost in Japan and whether or not the conditions for an equal footing with overseas countries will be available in Japan.

(iii) Use hydrogen as a raw material (chemical industry)

For the petrochemical industry, which uses naphtha as a raw material, the path toward carbon neutrality would be through the production of hydrocarbons, such as olefins and functional chemicals using CO_2 and hydrogen as raw materials. The production process eliminates the need for a naphtha cracking furnace and therefore CO_2 emissions and uses the CO_2 itself as a raw material. It is expected to eliminate not only Scope 1 and 2 emissions but Scope 3 emissions and to contribute to carbon neutrality throughout the entire supply chain. We will provide the support oriented toward establishing the technologies creating a market of CO_2-derived plastics ahead of the rest of the world.[42] Existing naphtha cracking furnaces emit a large amount of CO_2. To reduce CO_2 emissions, we will also support establishment of combustion technology toward replacing off-gas with ammonia.

[42] For example, 1.07 million tons of hydrogen are required to produce 1 million tons of ethylene, a raw material of various chemical products, using CO_2.

In parallel, we will develop policy measures for highlighting the environmental values of the technology; using CO_2, a GHG that is normally just emitted into the air, as raw materials and using renewable energy source-derived hydrogen in order to promote investments toward the use of CO_2 as the raw material and the use of ammonia fuel in naphtha cracking furnaces.

(2) Develop demand-side rules for replacing fossil energy sources with non-fossil energy sources

In Japan, the amended Energy Conservation Act[43] requires specified business operators to submit their medium- to long-term plans on the transition to non-fossil energy and to periodically report progress. Eight industrial sectors, which are classified into one of five industries, account for 40% of the total industrial energy consumption: steel industry (blast furnaces and electric furnaces); chemical industry (petrochemical and caustic soda manufacturing sector); cement manufacturing industry; paper industry (manufacturing and paperboard manufacturing sector); and the automobile manufacturing industry. The government will set the guidelines for the transition toward the use of non-fossil energy in order to encourage companies to make greater efforts. As for hydrogen, its contribution to carbon neutrality depends on its specific carbon intensity. As a part of the measures for the transition toward non-fossil energy, we will evaluate the specific uses of hydrogen for its contribution to carbon neutrality according to the carbon intensity beyond FY 2030, the existing target year defined in the Energy Conservation Act, and accelerate the transition toward clean hydrogen in the industrial sector.

(3) Use hydrogen as a hydrogen compound

e-methane and synthetic fuel (e-fuel) may be distributed through the existing city gas distribution networks and petroleum supply infrastructure. Those fuels may meet the fuel need in the iron-and steelmaking, chemical, and manufacturing industries, which have heat demand in the high temperature zone. To penetrate into the industrial segments, we will coordinate the development of international and domestic rules regarding the handling of CO_2 emissions associated with the combustion of those fuels. In addition, we will support research and development activities for those fuels, including non-fossil derived LP gas, through the GI Fund and develop the support program for their industrialization and cost reductions.

3-4. Establish support schemes for building large-scale supply chains

Triggered by the Russian invasion of Ukraine and the global energy crisis, countries have started huge investments in the hydrogen sector. As a hydrogen energy pioneer, Japan will step into the transition toward low-carbon hydrogen and develop a pioneering combined regulatory and supportive

[43] The Act on Rationalizing Energy Use and Shifting to Non-fossil Energy (Act No. 49 of 1979)

scheme in an accelerated manner and ahead of Asian countries. The projected scheme includes several pillars.

(1) Develop institutions for building large-scale and resilient supply chains

We will develop a supportive scheme for industrial operators that are willing to take the risk of investing in the low-carbon hydrogen and ammonia business ahead of other business operators, despite the uncertain prospect for the hydrogen sector, and plan to supply low-carbon hydrogen and ammonia in Japan by around 2030. Specifically, we will strategically select supply chains for those first movers from the perspective of S+3E guiding principles and the financial support scheme for (partially or fully) compensating the price gap between the strike price (a sufficient price to generate appropriate profits while reasonably recovering the costs required for business continuity) and the reference price (parity price of existing fuel) over the long term. At present, public and private sector investments in the supply chains are planned to exceed 15 trillion yen over 15 years.

Hydrogen production has several risks: the risks associated with raw material procurement and risk associated with a long payback period for large investment. To cover those risks, in the context of the amended Act on Japan Oil, Gas and Metals National Corporation (alias "Act of JOGMEC")[44] we will develop risk money support programs (investment/debt guarantee) for the hydrogen and ammonia production and storage projects undertaken by the Japan Organization for Metals and Energy Security (JOGMEC). Similarly, we will increase opportunities for blended financing, a combination of public funds and private capital. Specifically, we will develop financial support schemes from many public financial institutions, including the Japan Bank for International Cooperation, Development Bank of Japan, Nippon Export and Investment Insurance, and the GX Promotion Organization, which is expected to be established according to the GX Promotion Act[45] in order to mobilize significant funding.

As for CCS, the technology indispensable for low-carbon hydrogen production, we will move forward with CCS projects through the JOGMEC, which provides the geological structure survey, technical support, and risk money financing according to the amended Act of JOGMEC.

(2) Develop institutions toward construction of efficient supply infrastructures instrumental to demand creation

In order to contribute to creating large-scale demand and efficient supply chains, the enablers of stable and unexpensive hydrogen and ammonia, and to advance globally competitive industrial agglomeration, we will support the development of supply infrastructures, including tanks and pipelines. To develop efficient supply chains, hubs have to be deployed nationwide at the best locations. The hubs have to be developed in a manner commensurate with the local demand scale

[44] The Act on Japan Organization for Metals and Energy Security (Act No. 94 of 2002)
[45] The Act on Promotion of a Smooth Transition to a Decarbonized Growth-Oriented Economic Structure (Act No. 32 of 2023)

and industrial characteristics. To create extensive demand nationwide, the concentration and distribution have to be carefully arranged, and they have to be connected to their surrounding areas by ship or other means in a manner to create hub-and-spoke supply networks. Specifically, we plan to establish several large-scale bases in metropolitan areas, where significant industrial demand does exist, and five or more medium-scale hubs in each of the regions where substantial demand is anticipated against the backgrounds of their different industrial characteristics over the next ten years. Ports and coastal areas have the potential to create large-scale demand for hydrogen through the concentration of existing industries. They are also capable of efficient and large-scale transportation and subsequent storage using vessels. In addition, existing structures may be creatively utilized to efficiently create hydrogen hubs. For example, wharves reorganized in conjunction with changes in the industrial structure may give an opportunity. We will extend our support to the hinterlands to develop efficient supply infrastructures and to create more extensive demand.

Support activities should be coordinated from the supply chain construction support programs to the hub development support programs in order to build a large-scale hydrogen and ammonia supply chain. We will coordinate different support programs for that objective. For example, we may give preferential treatment to the supply chain building projects if they are combined with hub development projects. We may also coordinate the support programs with port-based initiatives, such as Carbon Neutral Port (CNP) plans and fuel-shifting support programs for decarbonizing the manufacturing industry to provide seamless support for the social implementation of hydrogen and ammonia.

3-5. Increase local use of hydrogen and coordinate with local governments

To produce and use hydrogen in specific geographical areas, it is important to construct local hydrogen supply chains by developing hydrogen production, storage, transport, and consumption facilities supported by local resources (renewable energy, by-product hydrogen, waste plastic, livestock manure, sewage sludge, and household waste) and infrastructure networks connecting those facilities in a locally rooted manner. Specifically, we should develop demonstration models that combine diverse local supply and demand in a manner to reflect local characteristics.

For example, in a local area where demand is dispersed, like inland areas, rather than the areas where port facilities and industrial complexes are concentrated, hydrogen utilisation will be promoted in all parts of the country, while also expanding regionally and areal-wise, through demonstrations and other activities aimed at establishing a self-sustaining, decentralised, local production for local consumption model where hydrogen is produced on-site using renewable energy and other local resources and used for diverse local demand (heat use, power generation, mobility, industry, business, households, etc.).

In addition, under the leadership of local governments, which are the drivers of local policies, close coordination and cooperation among local companies and related organizations and inter-local coordination at the national and international levels will provide opportunities to share and spread best practices and the lessons learned. Those coordinating efforts will boost hydrogen production using local resources and increase the use of hydrogen in response to increased and diversified demand. The Japan Hydrogen Association (JH2A), whose members include local governments actively working on the use of hydrogen, has an awards program for local governments to commend advanced hydrogen initiatives jointly pursued by the public and private sectors and to encourage inter-local coordination. In addition, the JH2A publishes various demonstration cases and hydrogen information through the website, etc. so that local governments and companies that are interested in the local use of hydrogen can see hydrogen supply chain construction model demonstrations based on local resources and share them among local governments. Under the Clean Energy Ministerial Hydrogen Initiative, the H_2 Twin Cities program has been launched to catalyze the use of hydrogen through the Mentor-Mentee Cities partnership.[46] In line with these efforts, the Japanese government will continue to offer proactive information dissemination and awareness raising activities to local governments. It will also propose support programs that are easy for local governments to join through planning support and environmental education. It will consider technology developments, renewable energy power supply costs, results of demonstration projects, and develop specific policy measures for several agendas by increasing regional hydrogen demand and optimizing supply and demand through cooperation with local governments and companies, accelerating the construction of hydrogen-related facilities and the use of existing infrastructure for cost reductions, and reducing running costs to develop and deploy regional hydrogen supply chains.

In particular, the Fukushima prefectural government, which advances hydrogen-based society model building as one of the key policies in its Fukushima Plan for a New Energy Society, signed partnership agreements with hydrogen businesses and other local governments in Japan and overseas and kicked off different efforts. In order to further accelerate these efforts, the Japanese government supports the prefectural initiatives. For example, it supports the Fukushima Hydrogen Energy Research Field (FH2R) to enable it to play a role as a central energy supplier in local revitalization programs. In addition, the Fukushima International Research and Education Institute (F-REI) will engage in research and development activities for building networks that makes full use of renewable energy and hydrogen across the areas on a locally producing and locally consuming approach as part of the creative community revitalizing programs in which hydrogen is positioned as one of the program pillars and as are undertaken in the Fukushima Hamadori and other areas. Located in Namie Town, F-REI engages in different demonstration programs, the use of pure hydrogen fuel cells in public facilities, hydrogen pillar pipelines, and hydrogen production and utilization facilities under optimal operation management systems. F-REI also signed memorandums of understanding regarding the collaboration with Lancaster City and Hawaii County. The Namie Town government has a plan to implement a hydrogen economy in the community by FY 2026 as a part of the revitalization initiatives for the Namie Station area, and it will promote the use of hydrogen around the revitalization initiatives.

[46] The partnership was signed between the twin Namie Town and two US municipalities, Lancaster City, California, and Hawaii County, Hawaii, and between Kobe City, and Aberdeen City, UK

Ammonia is another focus in Namie Town. Construction work will start there in 2023 under the support of the GI Fund to build a plant that produces renewable energy-derived ammonia. The plant will conduct a demonstration study for ammonia production by FY2026.

In Yamanashi Prefecture, the Power to Gas (P2G)[47] system started, and the model has been deployed domestically and internationally. Hydrogen-related companies have concentrated their research centers, which have a spillover effect on the local economy. The prefectural government established the Yamanashi Hydrogen Company (YHC)[48] with the private sector. It shares the skills with other prefectural governments through the company and aims to increase domestic hydrogen production and attract more customers in Japan. In parallel, it shares overseas leading practices, including the use of hydrogen as a heat source in India and Scotland, and is actively engaged in entering the international hydrogen market.

The Tokyo metropolitan government (TMG) uses the hydrogen produced in Yamanashi Prefecture to supply power to a governmental event facility (Tokyo Big Sight). It aims to raise awareness about hydrogen among the visitors and increase public acceptance for it. TMG budgeted a total of 3.6 billion yen (in the FY 2023 budget) for the Carbon-Neutral Port (CNP) projects around Tokyo Port, which includes support for the installation of fuel cell powered material handling equipment. TMG is one of the main drivers of hydrogen demand growth. The Fukuoka City government is a pioneer in creating hydrogen demand in the mobility sector. It plans to completely switch garbage trucks, food delivery trucks, and ambulances from conventional models to fuel cell powered versions. Those vehicles are all essential for the daily life of citizens. The Saga prefectural government proposed a multipurpose hydrogen utilization model to the central government. It conducted a demonstration experiment of the model, where FCVs would be used during nighttime construction work not only as a power source for lighting but as means to reduce noise and odor in the construction work ordered by the central government. It evaluated its usefulness and assessed the environmental impact. The initiative added impetus to use FCVs among small and medium-sized enterprises in the prefecture and major national gas companies, providing an example for the horizontal development of hydrogen utilization models.

3-6. Bring forward innovative technology development

The following innovative hydrogen technologies have to be steadily researched and developed in the areas of production, transportation, storage, and use through industry-academia-government collaboration in order to achieve the widespread use of hydrogen over the mid- and long-term periods toward carbon neutrality by 2050. In addition, it is also important to develop human resources who will lead future industries through research and development activities. In the context of technology development, the competent ministries and agencies will take into account international moves, promising seeds from basic research, and the needs of the industrial sector and bridge important

[47] Processes through which hydrogen is produced using electricity from renewable sources, stored, and used.
[48] Established in February 2022 by the Yamanashi prefectural government, Tokyo Electric Power Company Holdings, Inc., and Toray Industries, Inc.

scientific achievements made by universities and research and development agencies to companies and enable their social implementation in a concerted manner.

[Production]

High-efficient, high-durable, and low-cost water electrolysis technology, high-temperature heat sources, such as high temperature gas reactor, thermal decomposition of methane, and photocatalytic hydrogen production technology

[Transport and storage]

Efficient hydrogen liquefier, transport, and storage technologies, such as hydrogen storage alloys, technologies for reducing hydrogen carrier cost and ammonia cracking

[Use]

Efficient, durable, and low-cost fuel cell technologies, technologies for manufacturing Carbon Recycling products, including e-methane and synthetic fuel (e-fuel)

3-7. International coordination (standardization strategies, activities in multilateral frameworks)

(1) Efforts for standardization

ISO/TC 197 (international standards for hydrogen technologies) focused on developing international standards for hydrogen stations. In response to the recent increase in the use of hydrogen, additional initiatives were launched to develop international standards for water electrolyzers and methodologies for calculating greenhouse gas emissions from hydrogen production. Given the recent moves, we will strategically identify the areas that may require standardization efforts from the different perspectives of hydrogen supply chain construction and the impact on hydrogen-related industries. First of all, we will work on the standardization of auxiliary equipment, such as loading arms, and then take a core position in subsequent standardization programs other than ISO/TC 197; ISO/TC 22/SC 37 (electric vehicles), IEC/TC 105 (fuel cells), and IEC/TC 69 (electric vehicles and electric industrial vehicles). We have to develop the human resources capable of negotiating in the international standardization arena in order to ensure that the expertise and technologies achieved through enhanced hydrogen utilization in Japan contribute to carbon neutrality on a global scale. We will make the required contributions to international standardization, including human resource development. In the area of international standardization for FCVs, we will lead the development and revision of international standards on safety and fuel efficiency in close cooperation with the industrial sector in the UNECE World Forum for Harmonization of Vehicle Regulations (WP.29).

In the ISO/TC 67 (Oil and gas industries including low-carbon energy) development process, the Japanese delegation takes the lead in discussions for the international standardization of e-ammonia-related technologies, including ammonia combustion technologies that reduce nitrogen oxide emissions. They approach other national delegations and make specific proposals. We will accurately understand the strengths of Japan's ammonia-related technologies and advance concerted efforts with the private sector to develop forward-thinking international standards.

(2) Direction of international trading

In the early stage of LNG projects, the majority of LNG projects stood on the premise that LNG dedicated tankers would shuttle between production areas and consumption areas. The associated contacts, therefore, included clauses that specified the destination or take or pay clauses, which were all advantageous terms for sellers. More recently, buyers have increasingly requested abolishment of destination restrictions from sellers, claiming that they would reduce LNG market liquidity. In light of recent developments, rather than contracts advantageous for buyers that prevailed in the period when demand had not been established, for the international hydrogen trade, we should develop and standardize LNG contract models that do not include destination restrictions or that address the potential impact on prices and the risk of losing national wealth in an anticipatory fashion.

(3) Activities in multilateral frameworks

In 2018, the Japanese government held the first Hydrogen Energy Ministerial Meeting and since then has been leading the efforts required for increasing the use of hydrogen on a global scale. The Tokyo Statement, which was adopted at the meeting, and the associated Global Action Agenda set out the goals of 10,000 hydrogen refueling stations and 10 million fuel cell systems in the next 10 years. We share the ambitions with the countries involved and will work hard to create a hydrogen-based society.

Since it is difficult for a single country to establish a hydrogen market alone, multilateral frameworks have been mobilized to articulate the action plans. Indeed, since the hydrogen technologies will likely be applied over a wide range of fields, the Hydrogen Energy Ministerial Meeting, IPHE, the Clean Energy Ministerial Meeting (CEM), and Mission Innovation (MI) address the diverse agendas related to hydrogen technologies: the methodology for calculating greenhouse gas emissions from hydrogen production, international trade rules for hydrogen, H2 Twin Cities for expertise sharing, and Hydrogen Valley (a platform for presenting the initiatives for locally producing and locally consuming hydrogen).

As for ammonia, Japan hosted the International Conference on Fuel Ammonia from 2021. The event was intended to raise international awareness of ammonia because it does not emit CO_2 even when burnt and to increase demand. The event provided an opportunity to share the recognition of the need for building stable, inexpensive, and flexible fuel ammonia supply chains and markets among the participating countries. In line with this concept, we will communicate the importance of increasing both supply and demand of fuel ammonia in order to achieve carbon neutrality by 2050.

The G7, G20, Japan-US-Australia-India (QUAD), and the Indo-Pacific Economic Framework (IPEF) and other intergovernmental forums also include hydrogen and ammonia in their agendas.

As the market for hydrogen and ammonia is not yet mature, it is expected that international discussions on formulating regulations and standards, as well as presenting Japan's technology to other countries to show solutions (or, conversely, possibly obtaining solutions), and that will increase the international presence of the hydrogen and ammonia sector and at the same time increase the predictability of Japanese operators.

The Japanese government signed the Australia-Japan Partnership on Decarbonization through Technology with Australia. Japan hosted the ninth Pacific Island Leaders Meeting (PALM9), and the participating countries adopted the Joint Action Plan for Strengthening Pacific Bonds and for Mutual Prosperity. In line with the action plan, we will explore the possibility of green hydrogen projects in the Pacific Island region. We will also mobilize the technologies developed in Japan to support supply chain construction in developing and emerging countries. In January 2022, the Japanese government proposed the Asian Zero Emission Community (AZEC) vision to provide a framework for accelerating cooperation among Asian countries toward decarbonization. In 2023, the Japanese government hosted the first AZEC ministerial meeting and agreed to the AZEC joint statement where the AZEC partners jointly committed to accelerating the transition by building on their mutual trust. In the future, through harmonization of national policies, including standardization, and support for the development, demonstration, and deployment of decarbonization technologies, we will spread use of the innovative technologies, including hydrogen, and explore the possibilities of cost reductions.

3-8. Public acceptance

We have to improve public acceptance of hydrogen and ammonia technologies, governmental hydrogen and ammonia policies, and associated governmental support for companies. To this end, we should make more attentive efforts toward information sharing and constructive dialogs for Japanese people and municipalities. As a part of those efforts, we will extensively learn of the information sharing initiatives practiced in other countries and propose education and awareness-raising programs on ammonia and hydrogen. We will also provide the public, local governments, and businesses with more opportunities to improve their knowledge on ammonia and hydrogen.

Expo 2025 Osaka, Kansai World Expo, Japan, which will be held in 2025, will provide an excellent opportunity to widely showcase Japan's world-class technologies and deliver our vision of a future society. Hydrogen and ammonia will meet the electricity demand of the site, and fuel cell vessels will navigate around the venue to invoke the advent of a hydrogen-based society. We will step up public relations activities in cooperation with the private sector so that the public feels familiar with hydrogen through personal experiences and that public acceptance of hydrogen as one of the future energy sources will be enhanced.

Chapter 4 Direction toward Strengthening Competitiveness of Hydrogen Industry

4-1. Guiding Principles for Strengthening Competitiveness of Hydrogen Industry

In 2017, when the Basic Hydrogen Strategy was issued, Japan had created hydrogen demand ahead of the world. The nation had planned to develop industrial competencies at first domestically and embark on overseas markets. However, the landscape has drastically changed. For example, in the EU, regulatory measures, including taxonomies and carbon pricing, have been introduced and enhanced. As a result, the region became a market with a well-developed regulatory and financial infrastructure for a hydrogen economy. More recently, the Ukraine crisis has skyrocketed natural gas prices and threatened the stable energy supply. Now, Europe is facing the urgent need for hydrogen as an alternative fuel to natural gas. The global energy demand and supply markets have evolved. European countries have several programs, including the Green Deal Industrial Plan, which focus on developing the hydrogen industry. Those plans are designed to transform their national regional energy structures and create new markets for developing and deploying the hydrogen industry both domestically and internationally.

In the United States, the Inflation Reduction Act offers significant tax credits for clean hydrogen production over 10 years, attracting global attention to the potential leading hydrogen producer at once. Section 45Q of the Unites States Internal Revenue Code, which provides a tax credit for carbon capture and storage (CCS) projects, increased the exemption level up to \$85 per ton of CO_2 storage, which is the world's most significant tax incentive. In the US, the synergy effect of energy and industry policies is emerging. China currently has the world's largest demand for hydrogen, with an annual demand for hydrogen of approximately 33 million tons. Green hydrogen production is expected to increase in the future as renewable generation capacity grows.

In the recent global context, Japan will leverage its technological strengths to yield significant achievements on three fronts: decarbonization, stable energy supply, and economic growth. Specifically, we will implement the following hydrogen industry strategy and provide the momentum to bring Japan’s core hydrogen technologies (fuel cell, water electrolysis, power generation, transport, and material areas) across all hydrogen businesses in Japan and globally.

4-2. Hydrogen industry strategy

Hydrogen technologies and industries have gained ground worldwide, and the hydrogen-related market continues to grow. Against that background, our industrial policy should boost Japanese companies to penetrate their hydrogen technologies and products in domestic and overseas markets and to increase their industrial competitiveness. Earlier, in other words, during the fledgling period of the hydrogen market, we focused on demonstration projects in the different demand sectors in order to increase knowledge of the challenges for a hydrogen economy and to create initial demand. Despite the importance of continuing those efforts, the existing strategy should be reconstructed to enable Japanese companies to fulfil a commercial takeoff or establish themselves as competitive players both in Japan and overseas.

Domestic individual demand sectors yield limited demand and will not offer opportunities to drive mass production and cost reductions. The disadvantage may in turn curb demand growth. To overcome that feared vicious cycle, we should envision the domestic and overseas hydrogen markets in an integrated manner and establish business bases ahead of competitors in order to capture the market. The preemptive move will spur cost reductions and increase demand. We should push forward a virtuous cycle.

We should "win in technology and win in business as well." The hydrogen market segments may be characterized from two viewpoints: likeliness to function as a self-sustaining market with a large market size and the possible technological advantages of Japanese companies. We identify five types of hydrogen market segments (nine product types) as strategic focuses:

(1) Hydrogen supply (hydrogen production, hydrogen supply chain construction)

(2) Decarbonization of power generation

(3) Fuel cells

(4) Direct use of hydrogen (decarbonized steel, decarbonized chemical products, hydrogen-fueled ships)

(5) Effective use of hydrogen compounds (fuel ammonia, carbon recycled products)

In addition to supporting the hydrogen industry in the individual market segments, we will leverage the geographical and organic integration of local hydrogen businesses within specific local areas and regions to bolster growth in a holistic manner.

(1) Hydrogen supply

A) Hydrogen production

Driven by the recent global increase of interest in hydrogen, water electrolysis technology, a key technology for producing hydrogen from renewable energy sources, has been attracting acute interest. Along with the move, water electrolyzer manufacturers have been competing more intensely to commercialize the technology. They are now moving from the demonstration phase to the commercial phase in order to increase their market shares.

As for the water electrolyzer market, Japan is likely to exert its technological strengths in the areas of safe and stable operation of equipment and innovative materials and components. In addition to continued support for the industrial efforts to develop technologies to improve the performance and durability of electrolyzer components and materials, we will multiply our support in order to increase the scale of electrolyzer systems and the capacity of manufacturing the systems and their components and materials, support new water electrolysis technologies that include high-temperature steam electrolysis and anion exchange membrane (AEM) technologies, leverage the technological strengths of Japanese companies in the international standardization process, collaborate with overseas partners to step into overseas markets, and construct support systems involving the national government and agencies for project structuring. In particular, we should pour more efforts to increase the scale of electrolyzer systems and the capacity of manufacturing the systems and their components and materials. Construction projects for large-scale plants producing hydrogen from renewable energy sources and investments in the installation and manufacturing of large-scale water electrolysis systems are successively proposed and undertaken in the world. In order to strengthen Japanese competitiveness in the segment, the Japanese government will mobilize the GI Fund to support demonstration activities for developing larger-scale and modular electrolyzers and to develop effective supportive measures to upgrade the industrial capacity of manufacturing water electrolysis equipment, components, and materials.

(i) Reduce electrolyzer equipment cost and prices of hydrogen produced from renewables

Along with electric power cost reductions, equipment cost reductions and equipment upgrading are required to achieve the desired cost level for hydrogen production with water electrolyzers. In order to achieve the 2030 target of 52,000 yen/kW for alkaline electrolyzers and 65,000 yen/kW[49] for solid polymer electrolyte membrane (PEM) electrolyzers, we will continue to provide development support, including development of auxiliary equipment, such as rectifiers. If a gap with the existing target is observed in view of future technological developments and reductions in equipment costs worldwide, consideration will be given to revising the target appropriately.

If Japanese companies upgrade their capacity for manufacturing water electrolyzers and components and materials, they will be able to reduce equipment costs and increase the international competitiveness of their water electrolyzers. We will develop specific support packages for increasing the manufacturing capacity and build an integrated supply chain from raw materials to the assembly of electrolyzers.

In order to produce hydrogen from renewable sources at low cost, we will continue to bring forward the widespread use of renewable energy and procure a large amount of inexpensive surplus renewable energy to increase the operating availability of water electrolyzers. The use of surplus electricity for hydrogen production may be a solution to the challenges of industrializing renewable energy, including the lack of balancing energy and grid congestion. To increase the use, along with the continued support for the development of larger-scale water electrolyzers, we will move forward with the effective use of renewable energy and developing systems for increasing the operating availability of electrolyzers.

[49] Council for a Strategy for Hydrogen and Fuel Cells of the METI, Hydrogen and Fuel Cell Strategy Roadmap (March 12, 2019)

(ii) Promote new water electrolysis technologies (high-temperature steam electrolysis and AEM-type water electrolysis)

Alkaline and PEM types of water electrolysers are currently in the commercial stage, but new technologies are being developed around the world, including high-temperature steam electrolysis with extremely high electrolysis efficiency and AEM, which, unlike PEM, does not require precious metals for the catalyst. Another is AEM electrolysis, which does not require rear metal catalysts unlike PEM systems. The activities to develop the technologies should be pursued going forward, and at the same time, the conditions for maximizing their technological advantages should be explored through social implementations.

B) Construct hydrogen supply chains

The needs for transporting a large amount of hydrogen and significant transport infrastructure development are anticipated toward 2030. In light of the anticipation, we will upgrade domestic hydrogen production facilities and step up the development of human resources in related fields in order to strengthen our international competitiveness. We also will effectively capture opportunities to increase the presence of Japanese companies in overseas markets, including Europe, through cooperation with partner companies and sale promotions by senior government or company officials.

We will increase opportunities to capture overseas markets through quality standardization of hydrogen and other materials and through licensing agreements on the expertise and skills involved in the different processes of the supply chain.

(i) Challenges of hydrogen transportation technologies

Liquefied hydrogen, MCH, and ammonia are candidate transport carriers of hydrogen. These media, however, have their own advantages and challenges. At present, therefore, it is difficult to predict which one will generally prevail over the others from a long-term perspective. These transport media may be selectively used to meet a specific need in the industrial processes, transportation, and power generation. The transport media are expected to coexist across different uses according to their characteristics. We have to encourage competition among them and determine the prospects of those transport media from diversified viewpoints of international transportation costs, domestic delivery costs, energy conversion costs for dehydrogenation, life cycle assessment of CO_2, and safety. We will regularly and scientifically determine the progress of technology development and include the insights obtained in the decision-making for allocating R&D support resources.

(Liquefied hydrogen)

Liquefied hydrogen technology does not require energy for carrier conversion at the receiving site. It delivers high-purity hydrogen (99.999%) and allows the hydrogen to be directly used in industrial applications, including fuel cells and transportation equipment. Japan has already successfully produced hydrogen in Australia and completed large-scale marine transportation to Japan (Kobe) by the world's first liquefied hydrogen carrier (February 2022). We will bring forward the development of larger and more efficient hydrogen transport means, the development of international standards for commercial hydrogen transport vessels, and the accelerated social implementation of supply chains bound for Japan. We will also participate in developing supply chains in overseas markets at the early stage and work for developing liquefied hydrogen supply chains. In order to increase the visibility of Japanese companies in areas where they are ahead, we will develop plans for standardization in parallel and increase their market share by reinforcing their superiority in the market.

(Methylcyclohexane [MCH])

MCH is easy to handle because it is a liquid at normal temperature and pressure. The material characteristics allow for storage for a long time and for use in existing transportation means, including tanks, and the cargo handling infrastructure. Japan completed the world's first international transportation demonstration project. Hydrogen was produced and converted to MCH in Brunei, then it was transported by sea to Japan (Kawasaki port) where hydrogen was extracted at a dehydrogenation plant (December 2020). We will work on the development of dehydrogenation technology using existing refinery facilities and the construction and demonstration of international supply chains. We will also work on cost reductions in the hydrogen supply through the MCH supply chain. We will support the development and demonstration in the areas of innovative technologies that enable direct conversion of water and toluene into MCH and the effective use of unused heat energies and of large-scale marine transportation.

(Ammonia)

Ammonia already has existing supply chains available. They are used to transport fertilizers and raw materials for chemical products. The substance is relatively readily used for direct applications and as a hydrogen carrier. Because of the favorable characteristics, ammonia has a promising prospect for versatility. The extraction of hydrogen from ammonia requires large-scale cracking installations. We will support the development and deployment of related technologies. We will also encourage additional technology development and deployment activities for more efficient ammonia manufacturing processes and direct use in thermal power generation, industrial furnaces, and ships.

(ii) Develop technologies and enabling conditions for cost reduction in domestic transportation

Effective transportation technologies have to be selectively used according to the distance between the supply and demand areas of hydrogen, compressed hydrogen, liquefied hydrogen, MCH, and ammonia and the pipeline and hydrogen storage alloy. Supply chains that effectively mobilize renewable energy or unused local resources in a manner harmonized with local characteristics or supply chain models based on self-sustaining local-production and local-consumption cycles should also be developed in order to promote and increase the supply and the effective use of hydrogen. We will provide support to the activities to solve specific technical or cost issues and work to build optimized domestic supply chains.

Dedicated trailers equipped with high-pressure hydrogen tanks commonly carry compressed hydrogen if a hydrogen demand area is located at a substantial distance from a hydrogen supply area. Further technology developments are required toward additional manufacturing cost reductions of compressors and storage tanks. Marine transportation may be one of the promising solutions given that the transportation means are suitable for long-distance mass transportation.

Liquefied hydrogen, which has a volume approximately one-800th smaller than gaseous hydrogen, provides higher transportation efficiency, and is more suitable for transportation. In order to use liquefied hydrogen as an effective means to increase domestic transportation efficiency, we will boost several technology development efforts: the development of efficient liquefiers for liquefaction cost reduction and the development of containers capable of effectively suppress vaporization.

MCH, which is liquid at normal temperature and pressure, is easy to handle. The compound is more compatible with existing infrastructures, with transportation vehicles like tank trucks, railway infrastructures used for transporting petroleum products, and oil tank stations located in inland areas. We will boost the efforts to develop dehydrogenation equipment that is compact and installable in urban areas in order to contribute to more efficient hydrogen transportation to inland areas.

Ammonia is easy to handle because it is liquified at -33°C and has higher hydrogen density than other technologies, which make it a more promising option for efficient domestic coastal vessel transportation.

Hydrogen pipelines are more useful for relatively short-distance hydrogen transportation, for example, between nearby factories. Inexpensive and durable pipelines would contribute to reducing pipeline installation cost per unit. We have to boost the activities to develop these pipelines. Note that we have to revise and develop laws and regulations applicable to pipeline technologies in order to make relevant institutions available for the future hydrogen business.

Hydrogen storage alloys, which transport and store hydrogen by absorbing hydrogen atoms in alloys, are easy to handle because they can be stored in large amounts at a relatively low pressure and are suitable for stationary hydrogen storage. We will continue to support the technology development activities focused on the alloys that are inexpensive and capable of storing more amount per unit of weight of the alloy. If we develop innovative materials that allow for hydrogen storage at extremely high densities, the technologies that achieve hydrogen storage density equivalent to that of liquefied ammonia at room temperature and pressure are also expected to be available.

(iii) Maritime transport by ship

Carbon neutrality by 2050 is a globally shared goal. To reach the goal, we have to push forward creating supply chains for hydrogen and ammonia. To this end, both of the primary or international transport between overseas and domestic hubs and the secondary or domestic transport between domestic hubs and different parts of the country should be efficiently and stably carried out. Ships capable of long-distance and large-scale transport are essential for these operations. For example, a liquified hydrogen carrier succeeded in demonstration operations between Japan and Australia in FY 2021, and a technology development project subsidized by the GI Fund was kicked off in FY 2021 in order to increase the size of liquefied hydrogen tanks. The project plans to start demonstration operations in FY 2028 and commercial operations as soon as possible after FY 2030. Through these efforts, we will accelerate social implementation of the carriers that contribute to large-scale hydrogen and ammonia transportation. We will also increase the use of the carriers and establish the bases for building those carriers in Japan to contribute to stable supply chains.

(2) Decarbonized Power Generation

Triggered by the European Commission's rule that required natural gas-fueled power plants to emit no more than 270 g CO_2e/kWh, efforts to develop burners co-firing at higher blend rates have been underway along with the 30% cofiring or 100% hydrogen firing technology development. We have to develop and demonstrate burners that meet the EC requirement and to manufacture the burners on a commercial basis in order to strengthen international competitiveness in the world market. We will add cofiring hydrogen power generation technology at high blend rates to the R&D menu of the GI Fund to accelerate development. Hydrogen power generation technology has the advantage of contributing to decarbonizing the electric power sector by means of existing power plants. From the viewpoint of strengthening Japanese companies' international competitiveness, it is also important to make various cofiring and mono-fuel burner portfolios available in order to keep pace with different national or corporate decarbonization roadmaps. Small-sized gas turbines, which technically support the switch from cofiring to mono-fuel firing, are already available. For the large-sized gas turbine market, in which Japanese companies occupy the top share, we will also keep up with the international policy developments and flexibly respond to changing demand.

We have to try to reduce costs throughout the hydrogen supply chain by giving close attention to current technology development trends in the hydrogen supply in order to bring forward the widespread use of hydrogen power generation technology. To this end, we support demonstration efforts of the hydrogen supply chain and hydrogen power generation in an integrated manner through the GI Fund. The stable supply of hydrogen fuel is an urgent need for the commercialization of hydrogen power generation. Indeed, the Joint Hydrogen Policy Subcommittee and the Ammonia and Other Decarbonized Fuel Policy Subcommittee meetings proposed the construction of commercial supply chains through the support scheme for creating resilient and large-scale supply chains and the support scheme for hydrogen and ammonia supply infrastructure base development. The committees also proposed coordination with long-term decarbonized power auctions. Policy support will continue to be provided for the integration of supply and demand.

(3) Fuel cells

Fuel cells are used to power a variety of equipment, including automotives, ships, railroads, and cargo handling equipment at ports. They meet many different energy demands from homes, offices, and factories. We have to create a virtuous cycle of cost reductions and demand growth, a key pathway for future prevailing presence across many different fields.

Also, fuel cells are a field in which Japan has technological strengths, as it is the world's pioneer in research and development and has the highest number of patents in the world. We should pursue the reaching of the state where *we win in technology and win in business*, and to that end, we should quickly develop business plans and enable conditions to ensure that Japanese companies win in the global market.

The key is cost reduction. So far, our efforts were focused on individual market segments and separately undertook demonstration projects to create markets and the efforts to identify challenges. As long as the market remains segmentalized, we are unlikely to reach the mass production level and achieve the desired cost reductions. For example, a market research company projected the global fuel cell system market to have a size of approximately 327.8 billion yen in FY 2020 (of which the major stack market is of approximately 41.1 billion yen) and approximately 4.9581 trillion yen by FY2030 (the major stack market will be 803.1 billion yen).[50] The FCV segment will account for about 42%, the trucks and bus segment about 32%, stationary fuel cells about 19%, and the industrial vehicles and portable backup segment about 6%. Looking at the commercial vehicle market, for example, the global sales volume is projected to exceed 17 million vehicles, while the Japanese market size is projected to be just less than 800,000 vehicles (5%).

Given the estimates, we have to urgently build an industrial strategy that focuses on the domestic and overseas markets for fuel cells and the technology that is used not only in individual applications (FC trucks and buses, FC forklifts, ships, and railways, etc.) but also constitutes the core of the value chain and is used throughout the value chain. If Japan-made fuel cells are to be used for various FC applications around the world, Japanese companies would hold the key position in the value chains, drive market growth, accelerate cost reductions, and contribute to a decarbonized world.

[50] Fuji-Keizai Group “Future Outlook for Fuel Cell-Related Technology and Market in 2020” The FC system market includes application prices including some vehicle prices.

Specifically, we will promote initiatives based on three pillars: A) industrialize fuel cell business, B) establish strategies from a global perspective, and C) increase demand in Japan, the mother market. We will accelerate specific efforts in individual sectors ranging from mobility to stationary use and ensure that they are consistent with these major policy pillars.

A) Industrialize fuel cell business

For fuel cells, the cell is its core technology. The device consists of various auxiliary parts, including the separator and tank needed for supplying hydrogen. We have to build robust supply chains that include these supporting industries toward future full-scale mass production. In order for these industries to grow domestically and to push Japan in the position of a global hub for the fuel cell industry, we will foster the supporting industries and give incentives to building their business locations within Japan.

We will first strive to proactively and strategically penetrate into profitable markets and to establish ourselves in the market ahead of the rest. Specifically, we will focus on domestic and overseas ports, industrial complexes, and urban areas where demand for hydrogen is concentrated. We will strategically form and capture markets by putting it together with other hydrogen demand in cooperation with the private sectors. We will also increase the profitability of the fuel cell business. For example, automated driving technology, which helps reduce the labor burden, may be combined with fuel cell technology to mutually highlight the added value and bring synergistic effects. As a part of the efforts to strengthen international competitiveness of Japanese companies, we will develop the plan to bolster their industrial capacity of manufacturing fuel cells and components and materials.

(i) Support the fuel cell support industry

We should reduce the cost of the entire fuel cell system, including the stack. Cooperation with companies that manufacture peripherals other than fuel cell stacks is the key. The market segment would offer many opportunities to small and medium-sized enterprises and give a promising outlook for building an extensive industrial cluster around fuel cell stacks. We will support and boost the supporting industry in coordination with METI regional bureaus of economy, trade and industry.

(ii) Create co-benefits and enhance the business value of the hydrogen industry

Hydrogen costs remain higher than fossil fuels. We have to emphasize the potential role that hydrogen would play in solving the problems faced by customers, rather than its role as a substitute for fossil fuels, and overcome its relative inferiority in the price competition. Hydrogen offers co-benefits, including cleanness, benefit for worker health and solution to labor shortage. We will discover different needs and provide support through seamless inter-ministerial coordination in order to promote those co-benefits and collaboration.

(iii) Create demand clusters

The hydrogen industry faces limited transaction volume and supply centers. We have to create substantial clustered demands in order to trigger the virtuous cycle that boosts the cost reduction of fuel cells and the use of hydrogen in a synergetic fashion. Typical clusters include ports, industrial parks, and model cities. Those infrastructures may form geographic clusters. Carbon neutrality may also develop demand clusters. To meet heat demand, different industries may be horizontally clustered around hydrogen burners and boilers. We will selectively allocate policy resources to the projects that contribute to demand cluster creation.

B) Develop strategies from a global perspective

The global fuel cell system market is projected to grow to just less than 5 trillion yen by FY 2030, and the global fuel cell stack market is projected to grow to more than 800 billion yen on the time horizon.[51] Given the predicted market size, we should ensure that Japanese companies develop business strategies for not only operating in Japan but entering the global market from the beginning in the future in order to establish themselves as viable and competitive business entities. Countries are now in the takeoff phase of the hydrogen business. We should effectively penetrate the market in that early period. We will aggressively find opportunities for senior government officials to directly promote sales and strive to increase our market share through public-private partnerships.

We should also effectively implement the Open & Close Strategy in order to leverage the technological strengths of Japanese companies in anticipation of penetrating the global market. We will talk with companies with technological excellence and develop the mechanisms for effectively managing and utilizing technologies, including international standardization.

C) Increase demand in Japan, the mother market

Solid demand in Japan, the mother market, will provide the arsenal for Japanese companies to compete in the global arena. However, given that Japan enjoys relatively small-scale demand, we have to articulate creative policy measures to increase the market. We may pump strategic investments into certain regions where demand is concentrated.

First, among the ports, airports, and cities where demand is concentrated, we will specifically identify the areas that are willing to use fuel cells ahead of others. We will consolidate fuel cell demand with other hydrogen demand and support market fostering from a strategic viewpoint. In addition, we will offer comprehensive support for first movers, including the hydrogen supply, to business operators, logistics companies, shippers, and factories, which will take risks and use those technologies ahead of other private businesses.

[51] Fuji-Keizai Group *Future Outlook for Fuel Cell-Related Technology and Market in 2020*

(i) Mobility and power segments

The transportation sector accounts for approximately 20% of CO_2 emissions and is one of the most important areas where carbon neutrality efforts should be accelerated. Compared to EVs, FCVs have the advantage of longer cruising ranges and shorter refueling times. They are challenged by the high cost of hydrogen and fuel cells and the need for constructing hydrogen supply chains. Hydrogen is also expected to meet power demand for transporting heavy objects in harbors, warehouses, and factories.

From a global perspective, the EU and China are also aggressively engaged in increasing the use of commercial FC vehicles (introduction of fuel cells and conversion to fuel cells). In the United States, large-scale demonstrations of FC-powered port cargo handling equipment have been conducted. In Japan, we will leverage the fuel cell technologies and expertise built into passenger car manufacturing to develop commercial FC vehicles. We will envision various applications that are likely to demonstrate the operational advantages of FCs, including forklifts, port cargo handling equipment, railways, and airport vehicles, and increase the use of hydrogen-powered equipment. Railways, ships, aircrafts, construction machinery, agricultural and forestry machinery, and cargo handling machinery are likely to have higher demand going forward. We should exploit those promising applications to create FC demand and push forward decarbonization of port and airport services through inter-ministerial concerted efforts. In anticipation of demand growth in the different fields, we will promote the multi-use of hydrogen stations.

We supported the initiative to install hydrogen refueling stations in advance of deploying FCVs. In collaboration with Japan H2 Mobility (JHyM), the goal of 160 stations by 2020 was almost achieved. We will assume a wide range of usage scenarios compatible with projected hydrogen mobility demands and accelerate the construction of large-scale and multi-use hydrogen stations. We will promptly update the support scheme in reference to input from JHyM.

Solid demand in Japan, the mother market, will provide the most reliable arsenal for Japanese companies to compete in the global arena. However, given that Japan enjoys relatively small-scale demand, we have to articulate creative policy measures, such as strategic deployment in areas of concentrated need, to foster the market. Japan has technological strengths in the area of fuel cells, and the technology will be needed in any application. Rather, we should look at the market as an integrated entity beyond the boundaries of industries and position the fuel cell at its center and develop strategies aligned with the different characteristics of the market segments in the global market.

(Automobiles)

Our policy focus has been placed on an increase in the use of FCVs and the construction of more hydrogen stations. In addition to passenger cars, we will focus on commercial vehicles, which are likely to have more hydrogen demand and demonstrate the advantages of FCVs.

In order to increase the use of commercial vehicles, especially FC trucks, we have to find a path to go through the standoff involving the market players: automakers cannot make production investment plans without demand forecasts, hydrogen station operators cannot make station investment plans without knowing how many FCVs will operate, and transporters and shippers cannot make FCV purchase plans without FCVs and hydrogen stations available. We will organize a working group involving the public and private sectors, which will be drawn up a road map for FC truck production and availability through discussions where relevant stakeholders gather, and a pathway for their introduction will be clarified.

According to the amended Act on the Rational Use of Energy (Energy Conservation Act), specified carriers and consignors were required to submit medium- to long-term plans for the operation of non-fossil fuel powered vehicles and periodic reports to competent authorities, and we set out ambitious targets for them. We will encourage the transport sector to operate FC trucks (8 metric tons or less) in line with the regulatory requirement and targets. We will develop the plan to set out a conversion target for trucks (over 8 metric tons) from conventional fossil-fuel-powered to hydrogen powered ones and expectations for refueling infrastructure development if those targets are justified by the use of FCVs and associated outlook. In addition to the regulatory measures, in order to ensure that the market players mentioned above break through the "Mexican standoff," we will plan audacious support programs for the first movers, in other words, the transporters and shippers who make drastic investment decisions.

In addition to FC trucks, commercial vehicles (buses, taxis, and hired cars), and official vehicles (police cars) will also create future demand for hydrogen. FCVs are likely to more usefully fulfill the commercial or official missions than EVs because of their operational advantages of a longer cruising range and shorter refueling time. In addition, the development of hydrogen engine vehicles, which use hydrogen as fuel in internal combustion engine vehicles is underway in the area of passenger cars. In the mobility sector, including those vehicles, we will push forward increasing hydrogen demand through the concerted efforts of the public and private sectors.

We will bring approximately 800,000 passenger car-equivalent vehicles (hydrogen consumption of approximately 80,000 tons/year) to the market by 2030 and steadily build hydrogen stations and achieve an objective of approximately 1,000 hydrogen stations by FY 2030 (hydrogen station is discussed below).

(Railway vehicles)

Fuel cell railway vehicles will not only reduce greenhouse gas emissions in non-electrified sections but also eliminate the need for maintenance costs related to overhead lines and substation equipment in electrified sections. The vehicles would give a renewed impetus to increasing the use of hydrogen in the flow of people and goods.

Putting those advantages in perspective, we will propel development activities for fuel cell railway vehicles to solve technological challenges that include a longer cruising range, higher output, and downsizing and to solving the challenges to social implementation, including mass production and cost reduction. We will also bring forward the technology development and social implementation of integrated hydrogen stations, which leverage their versatile transportation node functions to supply hydrogen to diverse mobilities, and hydrogen transport by railways, which would boost decarbonization of the railroad sector and creation of hydrogen demand from other mobilities and hydrogen supply chain construction. Development and demonstration activities of fuel cell railway vehicles are underway in other countries as well. No fuel cell railway vehicles operable on the railroads for which strict requirements (e.g., vehicle standards, route conditions) are applied, as observed in Japan, have been developed. We will preemptively share the results obtained from R&D activities with domestic and overseas stakeholders and bolster Japanese railway vehicle manufacturers to penetrate the overseas markets in an advantageous position.

(Vessels)

Electric propulsion systems based on hydrogen fuel cells and batteries are an option for decarbonization of small- and medium-sized vessels, the majority of which are domestic vessels. Of these, hydrogen fuel cell ships are challenged by higher installation costs compared to conventional heavy oil-fueled ships and inadequate infrastructure for supplying hydrogen fuel and other energy sources. Development and demonstration activities, however, have already been conducted toward the practical use of hydrogen fuel cell vessel introduction. In light of these circumstances, we will propel the efforts to increase the use of ships that contribute to the decarbonization of domestic vessels.

(Decarbonization in ports)

As for ports, in the line with the amended Port and Harbor Act,[52] we will collaborate with industries that are concentrated in coastal areas and push forward the Carbon Neutral Port (CNP) initiative, which includes port function upgrade projects combined with decarbonization measures and the development of hydrogen and ammonia receiving terminals. Specifically, we will develop plans to strategically identify and develop hydrogen and ammonia receiving terminals, to boost use of hydrogen-powered vehicles, including cargo handling equipment at ports and heavy-duty vehicles that moves into and out of ports, and to support the efforts to construct hydrogen supply system for next-generation vessels.

[52] Port and Harbor Act (Act No. 218 of 1950)

(Hydrogen station development policy)

As for the development policy of hydrogen stations, in the context of recent increasing the applications where hydrogen is used, we should focus on the concept of a multi-use station, a station that not only supplies fuel to passenger cars but meets diverse fuel supply needs from commercial vehicles, ports, and local facilities. We will attentively review potential demand for the multi-use station and effectively discover the locations where demand and supply are locally integrated, which are best for the multi-use stations as a part of the efforts to bring forward construction of multi-use stations and the conversion of existing hydrogen stations to multi-use stations. In order to establish large-scale hydrogen stations, in particular, we will reinforce policy resources, including tax incentives. For example, in order to meet hydrogen fuel demand of heavy-duty 8-tonne or heavier FC trucks, we will deploy hydrogen stations along their common travel routes mainly in the four major metropolitan areas. To discover potential demand, we have to carefully identify and integrate individual local energy needs. Leadership of local stakeholders is critically important for the locally based task. For example, the Fukuoka prefectural government set up a public-private task force whose members are transport operators, shippers, and hydrogen station businesses. The task force works on finding ways to have more FC trucks operated in coordination with the Fukuoka Trucking Association. Similarly, other local governments also work to build up demand together with regional METI offices, Regional Bureaus of Economy, Trade and Industry. We will dynamically support their activities and accelerate optimal deployment of hydrogen stations to meet discovered hydrogen demands. In addition, we will reexamine the business feasibility of hydrogen stations in the light that the cost reduction and market penetration of HC passenger cars as achieved and projected at present have significantly deviated from the initial targets. We will revise the targets and develop the specifications[53] for hydrogen stations as necessary.

Regarding regulations, we will continue to put the highest priority on safety. At the same time, we will promote the streamlining and optimization for the inspection and testing methods, etc., and will reduce the cost of building and operating hydrogen stations through further regulatory reviews.

Regarding technology development, we will fully mobilize the technological competence and expertise built by developing hydrogen stations for passenger vehicles to contribute to increasing the use of hydrogen-powered commercial vehicles. We will also accelerate the development and demonstration of high-flow-rate hydrogen fueling technology to establish its technological feasibility. Technology development for cost reduction is another task. We will

[53] Hydrogen-powered vehicles have shorter cruising ranges if their on-board hydrogen tanks contain hydrogen at lower pressures. The production cost of the compressed hydrogen fuel, however, is reduced. Specifically, if the tank pressure is lowered from 70 MPa to 35 MPa, the amount of energy that a vehicle carries decreases by 40%, but the cost of the compressed hydrogen fuel may be reduced by 20%. We will examine the specifications taking into consideration the comparison and the business feasibility of reducing tank pressure to 35 MPa.

explore the possibilities of reducing part replacement frequency using steel materials that are less expensive and resistant to low-temperature and high-pressure hydrogen environments for hydrogen stations (such as SUS300 series), and revising the regulatory nickel equivalent requirement for steel SUS316 and SUS316L.

(ii) Consumer sector

Household fuel cells have merged as promising energy-saving devices that decarbonize household heat demand and effectively use heat. They may also serve as backup power source or balancing energy during a disaster. We will push forward the widespread use and cost reduction of household fuel cells and eventual participation in the supply and demand adjustment market. Through these policy measures, we will trigger an organic increase in the use of household fuel cells. At the same time, we will set out the path toward further increasing the use of commercial and industrial fuel cells and pure hydrogen fuel cells.

(Household fuel cells)

Recently, the household fuel cell cogeneration system (ENE-FARM)[54] has been recognized not only as an energy saving water heater but as a useful power source during disasters. It supplies electricity and heat even during power outages. The cogeneration system covers approximately 70% of the power demand of households where it is installed, contributing to peak power demand reduction. There is an episode indicative of its perceived advantages. Approximately 100,000 ENE-FARM units were bought at once in a capacity auction (for FY 2024). As demonstrated by the successful bid, household fuel cells may contribute to the power grid as a power supplier and energy balancing source. It is expected to play an additional role as the supply and demand adjustment market is developed.

The sixth Strategic Energy Plan set an installation objective at 3 million units in 2030. Given that less than 500,000 units have been installed to date, we have a long way to go before the goal is reached. From now on, we will demonstrate that the system may serve as supply power and energy balancing source in the power grid and ensure that its potential is fully delivered. In order to ensure that the sales of units go along on track independently, we aim to further reduce costs by 30% relative to the current cost level, in other words, to reduce the payback period to five years through improved volume efficiency, higher utilization of producing factories, and models installable in limited spaces in collective housing.

Household fuel cells contain a system that produces hydrogen through the gas reforming process, which increases its cost. If hydrogen is supplied directly to the fuel cell, the need for a gas reformer will be eliminated, and inexpensive pure hydrogen fuel cells will be possible. We will increase the use of household fuel cells by concentrating the promotion to markets that

[54] Household fuel cells were first sold in Japan in 2009, and a total of 480,000 units were shipped as of the end of March 2023.

are anticipated to grow in the future and where the technology has technological advantages. We will also support the development of basic technologies and evaluation technologies that would help enhance the performance, durability and low cost, etc. of the devices and push forward upgrading the units.

(Commercial and industrial fuel cells)

Commercial and industrial fuel cells offer higher power generation efficiency than existing cogeneration systems. They are likely to be widely accepted as cogeneration systems in factories, hotels, and hospitals, all of which have high-volume heat demand. In addition, they may be also used as mono-generators and are likely to attract more customers who have less heat demand. They are expected to be widely introduced in infrastructures, such as refuge facilities, data centers, airports, and ports, all of which are required to be resilient. They would contribute to cuts in peak power demand on the power grid. Furthermore, corporations committed to 100 percent renewable electricity (RE100) may use the cells as supplementary power sources for solar power generation in order to provide electricity to their buildings and factories. If a hydrogen supply network is available, the RE100 companies may fully utilize renewable energy resources and enjoy stable power regardless of weather or time zones. Commercial and industrial fuel cells are promising means of effectively utilizing unused biomass from food factories and sewage treatment plants. In anticipation of the potential demand, we will improve catalyst activity in order to bring power generation efficiency from 40% to 55%, the current level, to 60% by 2030. We will also drive technology development to reduce the cost to around 500,000 yen/kW.

(Direction of fuel cell technology development)

Japan led the world in the field of fuel cell technology development. In recent years, however, development competition has intensified mainly in the areas of power sources for heavy-duty commercial vehicles, such as buses and trucks. In order to provide the significant output needed by railway vehicles and vessels and to address the diversified applications, including construction machinery, agricultural and forestry machinery, and drones, we have to develop upgraded fuel cells capable of providing higher temperatures (up to 120°C) beyond the existing fuel cells. Also, we have to provide fuel cells with further technical advantages and downsize them.

Several challenges have to be addressed before we reduce fuel cell production costs: automated search for catalysts, digital transformation of manufacturing processes for mass production, and harmonized methodology for qualification. Specialized testing and analysis equipment are required to solve those issues, which would pose too heavy a financial burden on one single company or academic institution, and will be made available by the technical research association FC-Cubic (Fuel Cell Cutting-Edge Research Center Technology Research Association) and other hydrogen research bases in various regions on the assumption that the equipment will be jointly used among the members.

(4) Direct use of hydrogen

A) Decarbonized steel

In order to achieve carbon-neutral ironmaking, hydrogen reduction ironmaking technology, which replaces conventional iron ore reducing agents with hydrogen, has to be developed. Efforts toward social implementation of the technology have been accelerated around the world. Japan will enhance the support to deployment of low-carbon technology using hydrogen and to hydrogen supply infrastructure development as a step toward establishing hydrogen reduction ironmaking technology in Japan ahead of other countries and gaining ground with the technology in overseas markets. Also, we will enhance the international competitiveness of the Japanese steel industry, which directly or indirectly exports approximately 60% of its production volume.

B) Decarbonized chemical products

In order to achieve carbon neutrality in the chemical industry, we also have to develop the technologies that produce chemicals from sources other than naphtha. Hydrogen is required to produce hydrocarbons, such as olefins, and functional chemicals from CO_2. Hydrogen can avoid emissions of CO_2 produced from naphtha cracking. Hydrogen is expected to contribute to carbon neutrality throughout the entire supply chain, including not only Scope 1 and 2 emissions but also Scope 3 emissions by allowing CO_2 itself to be as a raw material. In addition to supporting the establishment of technology to realize a world-leading market for plastics and other products made from CO_2, Japan will also provide support for the development of hydrogen supply infrastructure, in order to strengthen its international competitiveness.

C) Hydrogen-fueled vessels

Widespread use of zero-emission vessels, which use hydrogen or ammonia as fuel is essential in order to achieve carbon neutrality in international shipping by 2050 and contribute to carbon neutrality in coastal shipping. In FY 2021, the technology development projects for hydrogen or ammonia-fueled vessels were started with financial support from the GI Fund. As fuel, hydrogen does not emit greenhouse gases when burned. If you try to obtain the same amount of energy as heavy oil from hydrogen, however, hydrogen reaches a volume 4.5 times greater than heavy oil. Hydrogen, therefore, would excessively occupy cargo space. In addition, hydrogen has a risk of abnormal combustion known as knocking. To solve these problems, we work on developing the engines, fuel tanks, and fuel supply systems that are compatible with hydrogen fuel. We plan to start demonstration operations in 2027 and commercial operations after 2030.

We will implement the set of measures necessary for the widespread use of zero-emission vessels in the fields of shipping, shipbuilding/marine use, and seafarers, the operation of zero-emission vessels, the construction of shipbuilding facilities within Japan, and seafarer education and training programs. In parallel with the initiatives, we will lead rule-making efforts on financial and regulatory measures in the International Maritime Organization (IMO). We will push forward widespread use of zero-emission ships and establishing regulations and institutions in an integrated manner.

(5) Hydrogen Compound

A) Fuel ammonia

We will support the efforts to increase supply and demand in order to build fuel ammonia supply chains. A limited number of licensors monopolize the ammonia production-related technologies and maintain an effective oligopoly. Against that background, several Japanese companies currently plan to enter into the international market through alliance agreements on ammonia production facility projects, for example, design, procurement, and construction projects, with overseas licensors. We will encourage specific project structuring. In addition, in anticipation that ammonia will be used in many different ways, we will support the technology development and demonstration projects of Japanese companies through the GI Fund toward the establishment of efficient ammonia synthesis technology. In particular, the support also includes start-up companies with impressive achievements. Indeed, some start-ups attracted significant funding to their innovative technologies from existing companies and accelerated technology development. We will negotiate collaborative support with global companies in the UAE and other countries in order to support the start-up companies in developing businesses according to their innovative business models. Once the Japanese companies establish their proprietary technologies through those support activities, we will disseminate the licenses to other countries and thus build the international competitiveness of Japanese companies around the world.

As for technologies for utilizing ammonia, a 20% co-firing test with a 1,000 MW actual plant is scheduled in FY 2023, and commercial operation is expected to start in the latter half of the 2020s. We will continue to support technology development and demonstration activities toward 50% or more co-firing and mono-firing and accelerate social implementation of those technologies. In the area of gas turbine technology, development of ammonia co-firing and single-firing systems, both small- and large-sized, is underway toward commercialization in the latter half of the 2020s. In addition, we will set out to develop international standards for the combustion technologies capable of emitting less nitrogen oxide and the fuel ammonia supply chains. In the countries with thermal power generation needs, we will contribute to reducing and eliminating CO_2 emissions from thermal power generation plants using ammonia from the early stage of the transition period and accelerate global decarbonization. Technology development has significantly advanced toward the use of fuel ammonia in industrial furnaces. We will use the ammonia technology to meet the heat demand in the areas where the demand is unlikely to be decarbonized through electrification and decarbonize the manufacturing industry.

Ammonia is expected to be extensively used as marine zero-emission fuel. Like hydrogen-fueled ships, technology development for ammonia is underway through the GI fund toward carbon neutral international shipping by 2050. Ammonia is liquified at -33°C, making it an easier fuel to handle than liquefied hydrogen. On the other hand, the compound produces nitrous oxide (N_2O) that has a global warming potential 300 times higher than that of CO_2 during combustion. Ammonia is also a toxic gas and therefore requires preventive measures against leakage. In order to solve these problems, engines, fuel tanks, fuel supply systems that are compatible with ammonia fuel are under development in Japan. As for ammonia-fueled vessels, the world's first engine combustion test for ammonia-fueled vessels was started in Japan in May 2023. We plan demonstration operations of ammonia-fueled vessels by 2026, followed by commercial operations as early as possible before 2028. We will implement the effective measures for widespread use of fuel ammonia in the areas of marine transportation, shipbuilding and marine use, and seafarers, bringing ammonia-fueled vessels into commercial use, construction of ammonia production facilities, education of seafarers, and development of enabling conditions.

Furthermore, ammonia is considered an attractive hydrogen carrier, and ammonia cracking technology is under development. Ammonia supply chains are projected to be available before long. Japan will accelerate development of efficient ammonia cracking technology in order to open the pathway toward using ammonia as a hydrogen carrier.

B) Recycled Carbon Products

Carbon Recycling technologies have the potential of effectively using CO_2 as resource, and they are among the key technologies to a carbon neutral society. Japanese companies have higher competitiveness in this area. e-methane, synthetic fuels (e-fuel), and other recycled carbon chemical products require hydrogen during manufacturing. The Carbon Recycling industry will serve as the direct means to reduce greenhouse gases, and at the same time, it will provide high-volume hydrogen demand. We will push forward with technology development and social implementation of Carbon Recycling.

Synthetic fuel (e-fuel) can be used together with existing internal combustion engines and oil supply infrastructure, and therefore the material is expected to be commercialized soon as recycled carbon fuel for automobiles, aircraft (sustainable aviation fuel), and vessels. In this context, we set a goal of achieving commercialization of synthetic fuel (e-fuel) in the first half of the 2030s. Specifically, we will accelerate the development of large-scale and highly efficient manufacturing technology using the GI Fund, support the domestic and overseas projects aimed at suppling synthetic fuel early using existing established technologies and encourage participation into those projects, develop plans to establish business models, and promote international standardization of fuel properties and rule-making of environmental value transfer through coordination with countries. In the third phase of the Strategic Innovation Promotion (SIP) program, we will bring forward research and development of Carbon Recycling mobile energy systems, which captures the CO_2 generated from synthetic fuel (e-fuel) and recycles it into synthetic fuel (e-fuel) in order to further reduce costs.

(i) Consumer sector

Bolstered by the advance of electrification toward decarbonizing household heat demand, we will increase the use of synthetic fuel (e-fuel) in the existing oil supply infrastructure and e-methane and non-fossil fuel LP gas in the existing city gas infrastructure.

As a part of the efforts to meet energy demand from households and small and medium-sized enterprises with non-fossil fuels, we will upgrade the existing Top Runner Program of the Energy Conservation Act in a manner to encourage non-fossil fuel producers to meet hydrogen specifications and electrification standards and increase the percentage that non-fossil fuel account for in the energy used in the equipment shipped by manufacturers over the medium to long term.

(ii) Decarbonization of aviation

We will develop demonstration aircraft by the 2030s, develop and demonstrate manufacturing technology for sustainable aviation fuels (SAFs), including synthetic fuel (e-fuel), use aircraft equipped with fuel-efficient and materials, and improve flight operations. In addition, we will continue to lead the efforts to establish international rules in this area, and the efforts to develop specific measures, including a framework for CO_2 emission reduction obligations under the UN agreement on the net-zero emissions by 2050. We will finalize the Basic Policy for Promoting Decarbonization of Aviation under the revised Civil Aeronautics Act[55] to promote the use of SAFs and create domestic and international demand for aircraft equipped with the new technologies. Specifically, in order to achieve the goal of replacing 10% of aviation fuel with SAF by 2030, we will set regulatory targets for the use and supply of SAF and support investment in SAF manufacturing infrastructure and technology development, and the construction of supply chains, including the procurement of raw materials. Our international gateway airports continue to drive decarbonization efforts of the reduction of CO_2 emissions from airport-related facilities and vehicles and the use of airports as renewable energy hubs. Other airports will develop airport decarbonization promotion plans according to

[55] The Civil Aeronautics Act (Act No. 231 of 1952)

the revised Airport Act[56] and will develop specific plans for the effective use of hydrogen taking their local circumstances into account.

[56] The Airport Act (Law No. 80 of 1956)

Chapter 5 Direction toward the safe use of hydrogen

5-1. Basic concepts for the safe use of hydrogen

In order to build a safe and secure hydrogen-based society, we first have to lay a solid foundation, in other words, safety, and build and maintain the house, in other words, promotion. According to the vision, we will leverage existing laws and regulations in order to facilitate construction a far-reaching hydrogen supply chain. In addition to clarifying and defining the nexus of the overall applicable laws and regulations, including safety regulations, we will speedily streamline and adapt the regulatory safety framework regulations and develop enabling conditions for a large-scale use of hydrogen across the society.

5-2. Hydrogen safety strategy

So far the use of hydrogen has been guided largely by applying the existing industrial safety regulations and other applicable laws and regulations. Although some regulatory enabling conditions for the use of hydrogen do exist, as those conditions are not necessarily based on the large-scale hydrogen utilization. Enabling the framework, including streamlined or adapted regulatory measures, should be constructed in anticipation of the widespread use of hydrogen. In order to accelerate the market penetration of hydrogen, the public and private sectors have to work together to thoroughly produce and collect scientific data and develop timely and economically reasonable and justifiable enabling conditions for hydrogen use. At the same time, they should effectively communicate Japan's technical safety standards to domestic and overseas stakeholders in order to build a seamless regulatory safety framework across the boundaries and to ensure globally harmonized rulemaking.

As a part of the efforts, a draft interim report for the Hydrogen Safety Strategy is under development with the intention of finalizing the report before the full-fledged use of hydrogen begins. The Hydrogen Safety Strategy is intended to provide action guidelines for the public and private sectors over the next five to ten years toward the construction of a safety regulation scheme covering the entire supply chains by 2050 (long term). The following initiatives will be implemented in accordance with the said strategy.

(1) Collect scientific data and evidence through technology development

A) Acquire scientific data strategically and share data on common areas

In order to claim safety to be the prerequisite of the use of hydrogen, we have to strategically acquire scientific data as evidence and be able to objectively demonstrate its safety. We will strategically acquire scientific data that would contribute to setting safety standards through state-of-the-art technology development projects financially supported by the national budget. Once demonstration projects are complete, the acquired scientific safety data, in principle, should be shared among the public and private sectors as shared knowledge.

B) Develop enabling conditions for smooth experiments and demonstrations

We will develop enabling conditions that facilitate demonstration tests to ensure that scientific safety data are smoothly acquired.

(2) Streamline and adapt rules toward gradual social implementation of hydrogen

A) Identify the supply chain segments to be prioritized

We have three criteria for identifying the supply chain segments that should be prioritized in terms of hydrogen safety: hydrogen and ammonia consumption, timing for starting to design the equipment related with hydrogen, and specific policy measures planned by governmental agencies, including demonstration projects.

B) Define the path to be followed [57]

We propose different approaches to the regulatory safety framework for two distinct phases: technology development and demonstration phase and the commercial phase. At the technology development and demonstration phase, we will apply existing safety regulations to expedite the processes. For the technologies at the commercialization phase, we will implement permanent measures including additional technical standards. We will ensure that the identical technical requirements are contained across the applicable laws and regulations in order to achieve the same safety level uniformly and develop a seamless regulatory safety framework. We will transition into a streamlined and adapted safety framework in order to reflect emergent business practices related with the use of hydrogen and associated business volumes, problems identified in the existing laws and regulations, and international trends over the medium to long term.

C) Set up and foster independent certification bodies and laboratories and support their capacity building efforts

We will set up and foster independent certification bodies and laboratories as core centers (CoE: Center of Excellence) integrating the skills, knowledge, and experience with hydrogen. The organizations are expected to plan and develop technical standards and to provide expertise and inspection service according to the technical standards. They will be underpinning social infrastructure for the upcoming hydrogen-based society.

D) Coordinate with local governments

[57] In the context of the guidelines for hydrogen safety, needs for the regulatory framework focusing on the issue and risk-informed technical standards were mentioned at the Working Group for Hydrogen Safety Strategy meeting.

In order to coordinate the gradual transition into the hydrogen-based society, the national government will support local governments in fulfilling their regulatory obligations to supervise industrial safety of high-pressure gas.

(3) Develop enabling conditions for use of hydrogen

A) Risk communication

Stakeholders involved in transition toward a hydrogen-based society have to join risk communication program, including information and education, taking into consideration the characteristics of different local areas in order to ensure that consumers and local population develop awareness and acceptance about physical properties of hydrogen, precautions for handling the substance, and safety measures.

B) Human resource development

It is important to recruit and retain the human resources who underpin safety and to develop the personnel who lead the discussions around hydrogen safety in Japan and the international arena. We have to develop the human resources in terms of competency and volume; therefore, we will build a talent pool who will build and support the hydrogen-based society. We will build a virtuous circle of expertise: the national government, business operators, and business associations support universities and research institutes and in turn the universities and research institutes develop human resources, enhance their skills, and supply the talent to those public and private sectors.

C) Grasp trends in the global market, harmonize regulations, and develop international standards

The public and private sectors should collect information and knowledge of current moves and enhance relationship with organizations involved through participation in bilateral and multilateral international conferences to come up with the recent moves in leading countries. In order to harmonize hydrogen safety regulations internationally, we will propose the candidate areas for developing technical standards and participate in the discussions.