The Strategic Road Map for Hydrogen and Fuel Cells

- Industry-academia-government action plan to realize a "Hydrogen Society" -

March 12, 2019

Hydrogen and Fuel Cell Strategy Council

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Chapter 1. General – Positioning the Basic Hydrogen Strategy and the Strategic Roadmap for hydrogen and fuel cells -

The fourth Strategic Energy Plan adopted in April 2014 stated, "a road map toward realization of a “hydrogen society” will be formulated, and a council which comprises representatives of industry, academia and government and which is responsible for its implementation will steadily implement necessary measures while progress is checked". Then, the Council for a Strategy for Hydrogen and Fuel Cells, which was held in June in the same year as a conference of expertss from industry, academia and government, compiled a Strategic Roadmap for Hydrogen and Fuel Cells (hereinafter referred to as "the Roadmap") presenting efforts to be undertaken by concerned parties from the public/private sector aimed at building a hydrogen-based society.

The Roadmap was revised in March 2016 in response to the progress of the efforts to include the schedule and quantitative targets to make the fuel cells for household use (Ene-Farm), fuel cell vehicles (FCVs) and hydrogen stations self-reliant.

In April 2017 the first Ministerial Council on Renewable Energy, Hydrogen and Related Issues was held. The Council decided to establish--by the end of the year--a basic strategy that would allow the government to press on with the measures in an integrated manner to realize a hydrogen-based society for the first time in the world. The second Ministerial Council on Renewable Energy, Hydrogen and Related Issues was then held in December of that year to establish the Basic Hydrogen Strategy. The Strategy was positioned as a policy through which the whole government would promote relevant measures and proposed that hydrogen be another new carbon-free energy option. By setting a target to be achieved by around 2030, the Strategy provides the general direction and vision that the public and private sectors should share with an eye on 2050.

Furthermore, the fifth Strategic Energy Plan was adopted in July 2018. In order for hydrogen to be available as another new energy option in addition to renewable energy, the Plan showed the correct direction of hydrogen energy in the energy policy, specifically, reducing the hydrogen procurement/supply cost to a level favorably comparable with that of existing energies while taking the calculated environmental value into account.

Description in the Basic Hydrogen Strategy (excerpts)

- According to the fourth Strategic Energy Plan adopted in April 2014 … the basic strategy includes the existing roadmap for the introduction and diffusion of individual technologies, positions hydrogen as a new carbon-free energy option and represents a policy that directs the whole of the government to implement relevant measures.
- In response to the effectuation of the Paris Agreement in November 2016 … based on the Strategic Roadmap for Hydrogen and Fuel Cells that mainly spells out goals to be realized by around 2030, this strategy provides the directions and vision that public and private sectors should adopt with an eye on 2050.

Description in the fifth Strategic Energy Plan (excerpts)

- In order for hydrogen to be available as another new energy option in addition to renewable energy, it is essential to bring down the procurement and supply costs of hydrogen, while incorporating the environmental value in the calculation, to levels that compare favorably with those of conventional energy sources.
- To that end, pursuant to the Basic Hydrogen Strategy, etc., Japan should accelerate an expansion of demand for hydrogen in mobility centering on fuel cell-powered vehicles in the immediate future, build an international supply chain across the full range of "production, storage, transportation and utilization" of hydrogen for mid- and long-term reduction of hydrogen costs, and proceed with technology development for the introduction of hydrogen-based power generation, which consumes massive amounts of hydrogen, in order to create a viable, demand-based, high-volume market for hydrogen which will allow for the operation of economies of scale, and in general, aim to utilize hydrogen not only in transportation but also in a wide range of sectors, including electric power generation and industry, as a non-carbon source of energy.

Based on the directions presented in the Basic Hydrogen Strategy and the fifth Strategic Energy Plan, the Roadmap adopted in March 2016 was considerably revised to reflect the new targets indicated in the Basic Hydrogen Strategy and the fifth Strategic Energy Plan, to achieve harmonization with the Basic Hydrogen Strategy, to specify the conditions and cost breakdown of the elemental technologies necessary for achieving the target, and to reflect the Tokyo Statement published in the Ministerial Council on Hydrogen in October 2018. In addition, the Roadmap specified concrete actions to be taken to achieve the target and included another action plan to be shared by the public and private sectors.

Public implementation of hydrogen technologies takes at least five years once they become technically possible to be commercialized. Taking this into account, it is important to have a future prospect, for example, setting up a technical development target within five years with an eye on the future possible society after ten years. This document provides a future milestones in the form of a road map, and then presents an action plan as a means of realizing it. The following chapters detail the new road map and the action plan.

This road map provides Japan's policy direction for realizing a hydrogen-based society as an important element of the Basic Hydrogen Strategy. It should be implemented by the public and private sectors working together and will be revised in conjunction with the Basic Hydrogen Strategy if required.

Chapter 2. Particulars for implementing the Basic Hydrogen Strategy

2-1. Hydrogen supply chain

2-1. (1) Achieving low-cost hydrogen procurement/supply

Hydrogen can be produced from a variety of energy sources including renewable energy and then stored/transported. It may be supplied from anywhere inside or outside Japan. In this sense, hydrogen has the potential of diversifying Japan's primary energy supply structure that relies heavily on fossil fuels from overseas, which constrains energy security due to the geographical and political risk factors this entails. Furthermore, by taking full advantage of CCS techniques and renewable energy in the hydrogen manufacturing processes, hydrogen can be a fully decarbonized energy source. In the use phase, we may also apply fuel cell technology that can efficiently produce electricity and heat from hydrogen, making it possible to achieve carbon reduction not only in transportation and electric power generation but also in other various fields including industrial use and heat utilization. To realize a society where hydrogen is massively used both in daily life and in industrial activities, it is indispensable to reduce the costs for hydrogen procurement/supply, while incorporating the environmental value into the calculation, to levels that compare favorably with those of conventional energy sources in order for hydrogen to be viable as another new energy option in addition to renewable energy.

Description in the Basic Hydrogen Strategy (excerpts)

- It is indispensable to reduce the hydrogen procurement and supply costs to realize a “hydrogen-based society” in which hydrogen is used in daily life and in industrial activities.
- Japan will reduce the cost of hydrogen to 30 yen/Nm3 … by around 2030.
- From 2030 … Japan will further reduce the cost ... in the future, Japan will try to lower the hydrogen cost to 20 yen/Nm3 to allow hydrogen-including its calculated environmental value-to have the same cost competitiveness as traditional energy sources.

Description in the fifth Strategic Energy Plan (excerpts)

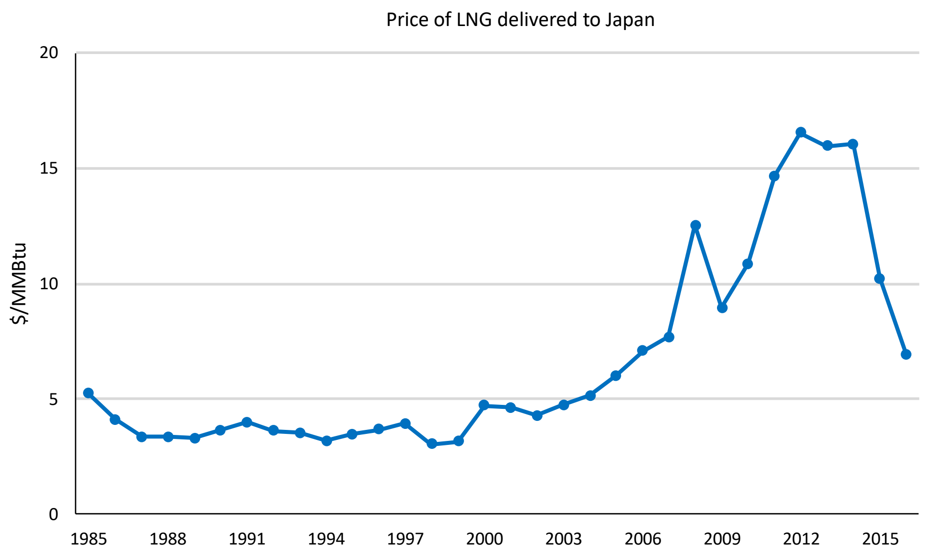
- In order to move ahead of the rest of the world in realizing a “hydrogen society,” it is essential to reduce the procurement and supply costs of hydrogen, while incorporating the environmental value into the calculation, to levels that compare favorably with those of conventional energy sources to ensure that hydrogen is viable as another new energy option in addition to renewable energy.

Hydrogen is a very promising means of achieving higher energy security and lower carbon emissions because of its diverse manufacturing methods and applications and absence of CO2 emissions in the use phase. Since the current hydrogen supply cost is higher than the existing energies including fossil fuel, however, it is essential to achieve low-cost hydrogen procurement/supply in order to expand the hydrogen utilization.

Based on these circumstances, the following road map and action plan outline a target hydrogen supply cost and specific measures to be implemented in reducing the cost:

<u>Road Map</u>

- Japan will try to introduce a full-scale supply chain from manufacturing to transportation/storage of hydrogen based on currently unused overseas energy sources in around 2030.
- Japan will try to reduce the hydrogen cost (plant delivery cost) to a level comparable to that of existing energy sources (with the calculated environmental value taken into account) while considering the LNG price trend toward the target hydrogen cost of about 30 yen/Nm3 in around 2030 and about 20 yen/Nm3 in the further future. For example, if the LNG price is $10/MMBtu (CIF price), the thermally-equivalent hydrogen price will be 13.3 yen/Nm3 without taking into account the environmental value calculation.



[Source] Prepared by Agency for Natural Resources and Energy based on a survey by the Energy Information Center

<u>Action Plan</u>

- Japan will continuously carry out development of fundamental technologies that will lower hydrogen costs and will try to achieve the required specifications and target costs for elemental technologies. (The target specifications of elemental technologies will be described later in this document).
- To ensure the availability of inexpensive overseas energy resources, in addition to private sector efforts, the Japanese government will try to build inter-government relationships to raise interest and secure resources.
- Japan will carry out surveys and analysis on the world's abundance of hydrogen supply sources (fossil fuels and renewable energy) and the possibility of their transport to Japan.

- Japan will carry out a survey to determine the potential hydrogen supply capability from using domestic byproduct hydrogen or other unused resources.

Supplement

In the Basic Hydrogen Strategy, Japan set its targets for reducing the cost of hydrogen to about 30 yen/Nm3 in around 2030 and then to about 20 yen/Nm3 in the later future. After the Great East Japan Earthquake, the price of LNG imported to Japan has ranged between $7 and $15/MMBtu, which is converted into about 9 yen to 20 yen/Nm3 of hydrogen on a calorific value basis. In addition, the World Energy Outlook 2018 of the International Energy Agency (IEA) forecasts that LNG prices in Japan will hover around $10/MMBtu (CIF Japan) in 2040. Based on these data, the target for the cost level of hydrogen needed to make it competitive with conventional energy sources is considered to be 13.3 yen/Nm3, equivalent to $10/MMBtu (CIF Japan) of LNG on a calorific value basis, while incorporating the environmental value of hydrogen into the price. The environmental value of hydrogen is calculated in many ways. Based on the New Policies Scenario of the World Energy Outlook 2018, the price of CO2 in East Asia for 2040 is estimated to be $44/t-CO2.

For these reasons, the target of future hydrogen prices should be set at 20 yen/Nm3 toward the full-scale social implementation of hydrogen energy. At the same time, it is necessary to further reduce hydrogen prices (including the environmental value calculation) to a level comparable with existing energy sources.

As to the environmental value of hydrogen in Japan, it is necessary to pay attention to international trends such as discussions on CO2 reduction targets in accordance with the Paris Agreement and examples in Europe where the production of low-carbon hydrogen is already being discussed. At the same time, the discussion on the environmental value of hydrogen should be continued with a focus on how to integrate it into laws and frameworks such as the Act on Sophisticated Methods of Energy Supply Structures, the Energy Saving Act, and the Act on Promotion of Global Warming Countermeasures, and on how to incorporate it into individual schemes and systems such as the Non-Fossil Value Trading Market, the Mandatory Greenhouse Gas Accounting and Reporting System, and the J-Credit Scheme, which were formulated based on the laws and frameworks above.

Meanwhile, it is also necessary to examine the potential of utilizing by-product hydrogen, which is produced at domestic oil refinery plants and chemical plants, as a source of cheap hydrogen. Other potential supply resources and costs of hydrogen should be studied through various types of surveys.

2-1. (2) Development of international hydrogen supply chain

Low-cost, untapped fossil fuel resources, which are abundantly available overseas, can be utilized as CO2-free energy by combining hydrogen production and CCS. For this reason, toward the realization of low-cost hydrogen supply, a project is currently underway to demonstrate the creation of an integrated hydrogen supply chain from production, to storage, transportation, and use. The operation is expected to launch in 2020 as a world first. A joint project currently being conducted by Japan and Australia aims to establish basic technologies through demonstration experiments for producing hydrogen from brown coal, which is a cheap, untapped energy source (using gasification technology) and for the ocean and land cargo transportation, handling, and storage of liquefied hydrogen. On the other hand, a project currently being conducted by Japan and Brunei is aimed at the establishment of basic technologies through demonstration experiments for hydrogen storage in liquid organic hydrides and dehydrogenation technology. Separately, a study on transporting hydrogen in the form of ammonia is underway. In addition, the Basic Hydrogen Strategy refers to a study on methanation using CO2-free hydrogen and domestic hydrogen pipeline transportation.

In order to realize an international hydrogen supply chain, Japan should take upstream approaches to acquiring of cheap and stable overseas energy resources including hydrogen production from renewable energy. In addition, Japan should systematically conduct research and development aimed at reducing costs in CO2 separation, collection, and storage.

Descriptions in the Basic Hydrogen Strategy (excerpts)

- Promising approaches to reducing the cost of hydrogen include … procuring massive amounts of hydrogen. They are basic approaches under which Japan will develop international integrated hydrogen supply chains covering everything from hydrogen production to storage, transportation, and use.
- Specifically, Japan will develop commercial-scale supply chains by around 2030 that will have the capacity to provide Japan with 300,000 tons of hydrogen annually and reduce the cost of hydrogen to 30 yen/Nm3.
- From 2030, Japan will expand international hydrogen supply chains on the supply side and spread industrial hydrogen use on the demand side to further reduce the hydrogen cost to narrow cost gaps with traditional energy sources. In the future, Japan will try to lower the hydrogen cost to 20 yen/Nm3 to allow hydrogen (including the environmental value calculation) to have the same cost competitiveness as traditional energy sources.

Descriptions in the fifth Strategic Energy Plan (excerpts)

- Promising approaches to reducing the cost of hydrogen include combining overseas unused energy with CCS and procuring massive amounts of hydrogen from cheap renewable energy. In order to realize the above, it is necessary, as upstream initiatives to secure cheap overseas resources, to exert private-sector efforts and pursue the development of relationships at the government-to-government levels, and also to develop energy carrier technologies to make the efficient transportation and storage of hydrogen possible, including liquefied hydrogen, methylcyclohexane (MCH), ammonia and methane. To that end, Japan will pursue the development of base technologies related to the production and transportation of hydrogen to make use of cheap overseas fuels, including brown coal, and develop commercial-scale international hydrogen supply chains by around 2030 to procure about 300,000 tons of hydrogen annually and reduce the cost of hydrogen to 30 yen/Nm3.

In creating a hydrogen supply chain, there are various options for energy carriers that can be chosen, such as liquefied hydrogen, organic hydride, ammonia, and methane. These energy carriers all have different characteristics, and have many technical, safety, environmental, and cost issues that need to be overcome. For this reason, it is necessary to promote research and development on these energy carriers with the aim of practical use, commercialization, and cost reduction.

For example, the establishment and cost reduction of a future commercial hydrogen supply chain using liquefied hydrogen as the energy carrier would require the increased capacity and efficiency of hydrogen receiving equipment (such as liquefied hydrogen storage tanks and loading arm systems) and other equipment including hydrogen liquefiers, liquefied hydrogen vaporizers, and boosting pumps. To meet these needs, the development of basic technologies in the related fields should be continued into the future.

Based on these issues, the following road map and action plans provide specification and cost breakdown targets for the fundamental technologies required in research and development and technical demonstration toward the creation of a hydrogen supply chain, and the specific measures that should be implemented to achieve such targets.

Road Map

- The following are the definitions of the target specifications needed for major element technologies that should be available by around FY2022.

  (1) Hydrogen production－The cost of hydrogen production by brown coal gasification[1] should be reduced from the current several hundreds of yen per Nm3 to 12 yen/Nm3 through efficiency improvements of brown coal gasifiers and others.

  (2) CCS

  －The practical use of CCS technology should be realized around 2020.

  －The technology that can collect CO_2 at a cost of the 2,000 yen level/t-CO_2 should be established around 2020 through research and development aimed at reducing the cost of CO_2 separation and collection, which account for most of the cost of the CCS process.

  (3) Storage and transportation

  － Appropriate fundamental technologies should be developed so that the capacity of an aboveground liquefied hydrogen storage tank can be increased from the current several thousands of cubic meters to 50,000m3.

  －The specific energy consumption for hydrogen liquefaction should be reduced from the current 13.6kWh/kg to 6.0kWh/kg.

  －To further reduce the cost of hydrogen supply using organic hydride after FY2030, the current toluene loss rate of 1.4% should be halved (this loss rate is calculated by [toluene consumption] / [toluene flow rate in the hydrogen supply chain] x 100%).

  －International rules for the ocean transportation of liquefied hydrogen should be established.

  (4) Use

  －The creation of an integrated hydrogen supply chain from production to storage, transportation, and use should be realized through research and development on ancillary equipment.

  －In anticipation of the use of hydrogen for power generation, the development of necessary technologies should be implemented (the details will be described later).

- Similar to recent approaches taken in Europe, as the near-term benchmark effective till FY2030 in creating a hydrogen supply chain, CO_2 emission reductions in the hydrogen production stage should be set at 60% of the level of CO_2 contained in hydrogen made from natural gas. In the future, CO_2 emitted from the hydrogen supply chain, from the mining stage of hydrogen resources through to consumption, should be reduced to virtually zero.

Action Plan

- Toward the realization and cost reduction of a commercial liquefied hydrogen supply chain, the

[1] The cost involved between hydrogen production by brown coal gasification and hydrogen purification (including the cost of brown coal as fuel and the cost of CO_2 separation and collection)

current development of necessary basic technologies should be continued until FY2022.

- Toward the realization of a hydrogen supply chain and future cost reductions, the following actions should be taken until FY2025 for each element of the hydrogen supply chain.

  (1) Hydrogen production

  －Research and development for large-scale and high efficiency brown coal gasifiers

  －Research and development for improvements in the efficiency and durability of water electrolysis (the details will be described later)

  (2) CCS

  －The demonstration of CO2 storage technologies; the establishment of monitoring technologies.

  －Research and development for low-cost CO2 separation and collection technologies

  －The promotion of international standardization in the fields of CO2 separation, collection, transportation, and storage

  (3) Storage and transportation

  －Research and development on large-scale liquefied hydrogen storage tanks

  －Research and development on large-scale liquefied hydrogen carriers

  －Research and development for improvements in the efficiency of hydrogen liquefaction

  －Research and development on large-capacity liquefied hydrogen loading systems

  －The deliberation on and formulation of international rules for the ocean transportation of liquefied hydrogen in the International Maritime Organization (IMO) based on the results of hydrogen supply chain demonstration available by FY2020.

  (4) Use

  －Research and development on large-capacity liquefied hydrogen vaporizers, boosting pumps, piping, and joints

  －Research and development on process optimization utilizing waste heat etc. for dehydrogenation of the carrier (the details will be described later)

  －Research and development and feasibility studies toward the realization of hydrogen power generation (the details will be described later)

- Concerning the CCS project that the Australian government and the Victorian government are conducting, the status of progress and the likelihood of success should be confirmed by FY2025.
- The challenges and achievements identified in the demonstration project of an international hydrogen supply chain to be completed in FY2020 should be made public in order to broadly provide effective feedback about how to reduce the cost of supplying hydrogen.
- Aiming at the practical use of CCS technology around 2020, the demonstration of large-scale CCS and a feasibility study on low-cost CCS should be implemented.
- In order to lead the ongoing discussions by ISO/TC265 on standardization in the fields of CO2 collection, transportation, and storage, Japan should proactively participate in such discussions.
- Toward the full-scale introduction of a commercial hydrogen supply chain in the future, a feasibility study and assessment should be conducted around 2025 with respect to the initial plan to reduce the

cost of a hydrogen supply chain to a level comparable with the cost of fossil fuels (with the environmental value of hydrogen included in the calculation), with emphasis on the import price of LNG in Japan. This process will be followed by a project implementation decision-making process.

- Toward the realization of further cost reduction in a commercial organic hydride-based hydrogen supply chain after FY2030, the development of necessary basic technologies should be continued.
- Research and development for CO2 emission reductions through the entire hydrogen supply chain should be conducted.

Supplement

As described in the Basic Hydrogen Strategy and the Strategic Energy Plan, expanded utilization of hydrogen would absolutely require reductions in hydrogen procurement and supply costs. The current demonstration project to be completed in FY2020 aims to establish the basic technologies needed to create an international hydrogen supply chain. But, in order to reduce the cost of hydrogen supply to a level compatible with conventional energy sources, the components used in the hydrogen supply chain would require significant cost reductions, scaling increases, and efficiency improvements. For example, in the case of hydrogen transportation in the form of liquefied hydrogen, the cost of hydrogen liquefaction accounts for as much as about 30% of the total cost of hydrogen. For this reason, there is the potential for a substantial decrease in hydrogen cost by reducing specific energy consumption for hydrogen liquefaction. In addition, when large quantities of liquefied hydrogen are stored at loading/unloading terminals in Japan and abroad, it does not make sense from an equipment cost standpoint to store the liquefied hydrogen in a large number of the lower-thousand-cubic-meter capacity storage tanks available today. Producing liquefied hydrogen storage tanks on the same scale as LNG storage tanks would contribute to cost reductions in the future. In the case of hydrogen transportation in the form of organic hydride, improvement in toluene loss rates through the entire hydrogen supply chain would make more business sense and contribute to cost reduction in the future. In order to realize these potential cost reductions and to ensure that the information is distributed as widely as possible to encourage constructive feedback, the issues and accomplishments identified in the demonstration project to be completed in FY2020 should be made public. Toward the creation of a commercial-scale, international hydrogen supply chain around 2030, appropriate research and development for hydrogen cost reduction should continue and a feasibility study and related assessment should be conducted around 2025 to see whether the realization of hydrogen cost reductions to a level comparable with fossil fuels is possible, upon which a decision on project implementation should be made based on the results.

In the meanwhile, new international rules should be established for the ocean transportation of liquefied hydrogen. In 2016, the International Maritime Organization (IMO) adopted the provisional safety standards Japan and Australia jointly proposed. In the future, based on the results of the hydrogen supply chain demonstration project to be completed in FY2020, international safety standards for the ocean transportation of liquefied hydrogen should be formulated.

When hydrogen is sourced from overseas, in addition to reducing costs, it is necessary to try to reduce CO2 emissions from the entire hydrogen supply chain. In the standards for low-carbon hydrogen currently under discussion in Europe, low-carbon hydrogen is defined as the hydrogen whose CO2 emission through its generation is 40% or lower compared to that generated during the current Best Available Technology (BAT) which is steam methane reforming of natural gas. With this definition set as the short-term benchmark effective until FY2030, CO2 emitted from the hydrogen supply chain, from the mining of hydrogen resources through to consumption should be set at virtually zero in the future.

Appropriate CCS-related technology development, cost reduction, and international standardization are especially important for the realization of decarbonization in the production and transportation stages of hydrogen production from fossil energy resources, and should be advanced toward the goal of the practical use of CCS technology.

2-1. (3) Expanded use of renewable-energy-derived hydrogen produced in Japan

According to forecasts by IEA and other institutions, due to the introduction of large quantities of renewable energy in the future, some countries will see oversupply of renewable-energy-derived electricity occurring throughout the year, requiring large-scale output control. In order to expand the use of renewable energy in the future, Japan may require both effective methods of securing electricity reserves and controlling output of renewable energy, and appropriate technologies to store surplus electricity for effective power utilization.

Power-to-Gas (P2G) technology, by which electricity generated from renewable energy is stored in the form of hydrogen, is drawing attention in Japan and abroad, particularly for its potential to mitigate long-period output fluctuations that occur across different seasons, for which current storage battery technology will be inadequate.

Given this background, many demonstration projects using large-scale water electrolysis are underway in Germany and other European countries. In Japan, a hydrogen production facility is currently under construction in Namie, Fukushima, toward the full-scale demonstration of Power-to-Gas technology. The facility, called "Fukushima Hydrogen Energy Research Field (FH2R)," is equipped with a 10MW water electrolysis unit, one of the largest of its kind in the world.

Success in the introduction of more renewable energy using Power-to-Gas technology and in the utilization of local renewable resources hinges on system optimization, cost reduction for water electrolysis, improvements in efficiency and durability, and the establishment of efficient system operation. On the other hand, the realization of reductions in equipment costs, operating costs, and the resulting hydrogen production costs, which will drive self-sustaining market penetration of Power-to-Gas systems including water electrolysis, is heavily influenced by external factors such as the scale of renewable energy introduction, power generation cost, and utilization rates. Therefore, the cost target for water electrolysis, whose cost could be reduced with the help of technical development, is stipulated In the Basic Hydrogen Strategy, with the commercialization of hydrogen production set to start around 2032, when new hydrogen production programs are expected to emerge after the period ends in which the total amount of power generated under the FIT scheme is purchased.

Descriptions in the Basic Hydrogen Strategy (excerpts)

- Cost reduction is the key to the full-scale use of hydrogen from renewable energy in Japan. The cost structure for hydrogen from renewable energy covers (1) operating expenditures for providing electricity from renewable energy sources, (2) the capacity utilization rate of hydrogen production equipment, and (3) capital expenditures on water electrolysis and other equipment. The first and second depend on future expansion of renewable energy. To reduce the third cost, Japan will promote equipment sales not only in the domestic market but also in overseas markets including Europe where renewable energy expansion and cost reductions have made faster progress than in Japan. Japan will also aim to establish technology that will cut the unit cost for water electrolysis systems as core power-to-gas equipment to 50,000 yen/kW by 2020 to realize the world's highest cost competitiveness.
- From 2020, Japan will promote the commercialization and installation of power-to-gas systems to store surplus electricity from renewable energy, based on the achievements of a pioneering demonstration project, which is being implemented in Fukushima Prefecture in order to promote the reconstruction of the prefecture. Japan aims to commercialize power-to-gas systems by around 2032, when the period of time for purchasing all electricity from renewable energy power generators under the Feed-in Tariff system will begin to expire for renewable energy projects. Furthermore, Japan will aim to reduce the cost of hydrogen from renewable energy to a level that is as low as that of imported hydrogen.

Descriptions in the fifth Strategic Energy Plan (excerpts)

- For the expansion of use of renewable energy going forward, technology for storing surplus electric power is a key component. Hydrogen, which makes the large-scale and long-term storage of energy possible, has the great potential to perform that role, and the power-to-gas (P2G) technology that stores electricity from renewable energy as hydrogen is effective in coping with long-period changes longer than one season, which are difficult for storage batteries to handle. As it is important to reduce the costs of related facilities and equipment for full-fledged utilization of hydrogen from domestic renewable energy, Japan will push ahead with commercialization not only in the domestic market but also in overseas markets, including Europe, which has a lead over Japan in terms of the amount of renewable energy introduced and costs. In addition, Japan will also aim to establish the technology that will cut the unit cost of water electrolysis systems, the core of P2G technology, to 50,000 yen/kW by 2020 to realize the world's highest cost competitiveness.

- In addition, from 2020 onward, Japan will promote efforts toward the commercialization and installation of P2G systems from the perspective of storing surplus electricity from renewable energy, based on the achievements of a pioneering demonstration project currently being implemented in Fukushima Prefecture. Japan aims to commercialize P2G systems by around 2032.

In accordance with the future direction stipulated in the Basic Hydrogen Strategy and the fifth Strategic Energy Plan, Japan targeted a water electrolysis system cost of 50,000 yen/kW so that it could maintain the world's highest level of competitiveness in the field of hydrogen production through water electrolysis. In addition, as part of its road map and action plans, Japan set the world's highest specification and cost targets for water electrolysis that Japan should realize, referring to the target values for water electrolysis proposed by FCHJU[2] and the U.S. Department of Energy (DOE). As such, the specific actions that Japan should take to achieve these targets are shown below. The actions that local communities and cities should take toward the realization of a "hydrogen society" are also shown below, including the utilization of Fukushima Hydrogen Energy Research Field (FH2R).

Road Map

- In addition to the target cost of 50,000 yen/kW for water electrolysis systems, each of two types of water electrolysis – alkaline water electrolysis and polymer electrolyte membrane (PEM) water electrolysis[3] – should meet the target values[*1] listed in the following tables.

Alkaline Water Electrolysis

[2] Fuel Cells and Hydrogen Joint Undertaking

[3] There are two major types of water electrolysis commercially available today on the market: alkaline water electrolysis and polymer electrolyte membrane (PEM) water electrolysis. While alkaline water electrolysis systems are suited for large-scale and relatively low-cost applications, the downsides of this type include the relatively slow response times to surges of input power and its large footprint. On the other hand, PEM water electrolysis systems respond quickly to surges of input power and can be downscaled easily, but they have higher costs. The type of water electrolysis is chosen depending on the purpose of the site.

Item		Unit	2020	2030
System	Energy consumption	kWh/Nm3	4.5	4.3
	Equipment cost[*2]	10,000 yen/Nm3/h (10,000 yen/kW)	34.8 (7.8)	22.3 (5.2)
	Maintenance cost[*3]	yen/(Nm3/h)/year	7,200	4,500
Stack	Degradation rate[*4]	%/1000h	0.12	0.10
	Current density	A/cm2	0.7	0.8
	Cobalt contained in catalyst	mg/W	3.4	0.7

*1 These target values are based on the use of a system that produces hydrogen in accordance with ISO14687-2 (3MPa) from 6kV alternating current and city water. Note that these values may change under different operating conditions.

*2 100MW production volume for single system supplier is assumed, and the system is assumed to operate stably for 10 years. The system is installed at a site with properly constructed foundations. This equipment cost includes transformers and rectifiers, but it does not include the cost of replacing stacks.

*3 The average of maintenance cost over 10 years. These values include the estimated cost of replacing stacks but do not include electric power charges.

*4 For example, the stack degradation rate of 0.125%/1000h means that when the system is operated 8,000h per year, energy consumption will increase by 10% over 10 years.

Source: Prepared based on "FCHJU Multi-Annual Work Plan 2014–2020"
at an exchange rate of 130 yen/€

Polymer Electrolyte Membrane (PEM) Water Electrolysis

Item		Unit	2020	2030
System	Energy consumption	kWh/Nm3	4.9	4.5
	Equipment cost	10,000 yen/Nm3/h (10,000 yen/kW)	57.5 (11.7)	29.0 (6.5)
	Maintenance cost	yen/(Nm3/h)/year	11,400	5,900
Stack	Degradation rate	%/1000h	0.19	0.12
	Current density	A/cm2	2.2	2.5
	Noble metal contained in catalyst (PGM[*1])	mg/W	2.7	0.4
	Noble metal contained in catalyst (platinum)	mg/W	0.7	0.1
Others	Hot start[*2]	Sec	2	1
	Cold start[*3]	Sec	30	10
	Footprint	m2/MW	100	45

*1 PGM stands for platinum group metals

*2 The time needed to reach a nominal output value from the standby mode, which is measured at an outside temperature of 15ºC.

*3 The time needed to reach a nominal output value after starting operation at an outside temperature of –20ºC.

Source: Prepared based on "FCHJU Multi-Annual Work Plan 2014-2020"
at an exchange rate of 130 yen/€

Action Plan

- As for water electrolysis technology, appropriate technology development should be conducted to further improve current density, efficiency, and durability based on accomplishments from the NEDO projects that are currently underway.
- To further improve current density, efficiency, and durability, the reaction mechanism of water electrolysis including the reaction for cell degradation should be better understood, and durability assessment techniques should be studied and standardized. The results from these efforts should be fed back into the ongoing technical development.
- Appropriate technologies should be developed allowing for optimal operation of the system based on various factors including technologies for predicting electricity generation from renewable energy, electricity supply-demand balancing, and predicting hydrogen demand.
- Depending on regional characteristics including local progress of renewable energy introduction and the form of hydrogen utilization, the potential for introducing a Power-to-Gas system should be studied including the need for the injection of hydrogen into gas pipelines or methanation.
- The current status of overseas Power-to-Gas systems (mainly European systems) should be surveyed.
- The public implementation of hydrogen-related technologies should be promoted intensively at several locations in Japan including Fukushima Prefecture, where the Fukushima Hydrogen Energy Research Field (FH2R) is located. These locations should be widely publicized in Japan and overseas as model cities and regions for the realization of a “hydrogen society.”

Supplement

Many demonstration projects using large-scale water electrolysis are underway in Germany and other European countries. In Japan, a hydrogen production facility is currently under construction in Namie, Fukushima, toward the full-scale demonstration of Power-to-Gas technology. The facility, called "Fukushima Hydrogen Energy Research Field (FH2R)," is equipped with a 10MW water electrolysis unit, one of the largest of its kind in the world.

The FCHJU, which is a public-private partnership that is promoting research and development and demonstration projects in the fields of hydrogen and fuel cells in Europe, which leads the world in the demonstration of Power-to-Gas systems, and the U.S. Department of Energy (DOE) already publicly presented their development targets for water electrolysis. Taking the target values presented by the FCHJU and the DOE into consideration, Japan has renewed its specification and cost targets for the elemental technologies that it should pursue in order to reach the world's highest level of competitiveness in the field of water electrolysis.

For example, the following are important approaches to reducing the cost of water electrolysis: 1) increasing current density to further improve the ability to produce hydrogen without changing the size of water electrolysis facilities, and 2) developing separator membranes, electrolyte membranes, and electrodes that can endure sudden fluctuations of electric power output and repeated start-stop operations. With respect to alkaline water electrolysis, the durability of the separator membrane and gas separation performance should be enhanced to improve system capabilities. For PEM water electrolysis on the other hand, improvement in electrode durability under load fluctuations, thinner polymer membranes, and reductions in the amount of noble metal catalyst should be pursued.

To make this happen, the issues and accomplishments identified from the Power-to-Gas demonstrations in the currently underway NEDO projects should be made public so that effective feedback will be provided to help promote the necessary technical development. It is also important to promote technical development by analyzing reaction mechanisms such as cell degradation, which are not fully understood to date, and by standardizing durability assessment techniques. These items should be pursued jointly by the private and public sectors.

In addition, because many countries are actively involved in research and development for the field of Power-to-Gas systems, information about the progress in these activities should be obtained appropriately so that information on global progress will be reflected in the efforts in Japan including the selection of the best locations for Power-to-Gas operations and the details of technical development and demonstration projects. As an example, in Europe, a small amount of hydrogen produced by water electrolysis is being injected into existing gas pipelines on an experimental basis. At the same time, a study on methanation, by which methane is synthesized from hydrogen and carbon dioxide, is currently underway in Japan and overseas. By understanding the latest status of technical developments like these, the potential for incorporating such technology should be studied including the need for implementation.

With respect to Fukushima Hydrogen Energy Research Field (FH2R), which is currently under construction in Namie, Fukushima, a technical demonstration of Power-to-Gas will be conducted using this facility, and there is a plan to use hydrogen produced at this site during the Tokyo 2020 Olympic and Paralympic Games. Also, there is an initiative/plan for the public implementation of hydrogen-related technologies, in which Fukushima is positioned as a model region for a future “hydrogen society” in Japan and hydrogen produced at FH2R will be used across Fukushima after 2020. Toward the realization of a “hydrogen society”, the projects designed to promote the public implementation of advanced technology are important as research and development for the practical use of such advanced technology. In addition to Fukushima, with the center of hydrogen production development mainly at FH2R, there are other regions in Japan where local governments, universities, and other entities have been working on the introduction of hydrogen and fuel cells since the days of the Sunshine Project and the Moonlight Project. These locations should also be widely publicized in Japan and abroad as model cities and regions for a "hydrogen society" by intensively promoting the public implementation of hydrogen-related technologies.

2-1. (4) Utilization of local resources and regional revitalization

Untapped resources such as locally produced renewable energy, waste plastic, sewage sludge, and by-product hydrogen have the potential to be utilized as supply sources of low-carbon hydrogen. A number of projects that will use such untapped resources are currently underway thanks to cooperation between local governments and private companies.

Descriptions in the Basic Hydrogen Strategy (excerpts)

- The development of hydrogen supply chains utilizing unused regional resources will contribute not only to expanding the use of low-carbon hydrogen in the future but also to improving regional energy self-sufficiency rates, creating new regional industries and establishing dispersed renewable and other energy systems on isolated islands with relatively small power systems.

Description in the fifth Basic Energy Plan (excerpts)

- Furthermore, leveraging the characteristic of hydrogen that it can be made from a variety of resources, some local governments are moving ahead with efforts to build hydrogen supply chains of the local-production-for-local-consumption type designed to convert unutilized regional resources (by-product hydrogen, renewable energy and sewage sludge, etc.) into hydrogen for use in FCVs and fuel cell forklifts. These efforts should lead to regional revitalization through the creation of employment and regional industries, in addition to their significance in terms of energy and environmental policies, including decarbonization and higher energy self-sufficiency rates in rural and isolated regions.

As cost effectiveness is essential in creating a hydrogen supply chain that is able to utilize local resources, efforts should be made to 1) improve the equipment utilization rate by boosting local demand and optimize local supply and demand for hydrogen, 2) reduce the cost of hydrogen-related infrastructure and 3) reduce the running costs of those facilities by reducing the costs of power generation and raw material procurement. As an action plan, therefore, the following should be carried out to create a supply chain in each region.

Action Plan

- Japan will communicate the outcomes of demonstration projects, etc. (the effects and costs of reducing greenhouse gas emissions) and create a low-carbon hydrogen supply chain model that leverages local resources to be shared among municipalities.
- Japan will educate municipalities by providing information on the use of hydrogen-based distributed energy supply systems in times of disasters (under the government initiative).
- Japan will try to reduce the costs of core technologies (i.e., water electrolysis), optimize the scale of production and standardize components and techniques based on forecasts of local demand for hydrogen and the market size of distributed energy systems that can leverage local hydrogen production.

Supplement

While municipalities should play an active role in creating hydrogen supply chains that leverage local resources, it is essential that they be educated properly and provided with information on the results of demonstration projects and the use of hydrogen-based distributed energy supply systems in cases of disasters. Thus, considering the results of the demonstration projects, the cost of green electricity and technological development trends in hydrogen infrastructures, measures to promote distributed low-carbon hydrogen supply chains leveraging local resources should be reviewed and discussed.

2-2. Hydrogen utilization

2-2. (1) Use in power generation

In order to reduce carbon in the power generation sector that accounts for 40% of Japan's total CO2 emissions, Japan will have to shift to an energy system in which renewable energy is positioned as one of its baseload power sources. It must be noted that current, large-scale renewable energy power generation alone fails to meet most of the power demand and must be accompanied by responses to massive oversupply periods (kWh), regulated power supply systems to control fluctuations (ΔkW) and backup power sources to prepare for renewable energy shortages (kW/kWh). Natural gas power generation features supply and adjustment capacity and for this reason is indispensable for renewable energy power generation expansion. However, hydrogen power generation can work in the same way as natural gas power generation and may become a leading option to reduce carbon in fossil power generation, assuming future cost reductions.

With this as a backdrop, elemental technologies for hydrogen co-generation to commercialize hydrogen power generation are being developed and demonstrated in the current NEDO projects. For off-grid power generation, for example, a demonstration program started in January 2018 for a 1 MW level co-generation system, followed in April 2018 by the world's first urban co-generation system using gas turbines fueled exclusively by hydrogen. At the same time, combustors for large-scale power generation are in the development pipeline, while combustion tests succeeded in January 2018; co-combustion technologies are nearing completion along with technologies for hydrogen co-generation. Mixed combustion of hydrogen is indeed technologically feasible.

With these approaches progressing, the Basic Hydrogen Strategy sets directions for the development of new combustion technologies, focusing on further improving the environmental performance (reduction of NOx emissions) and power generation efficiency, and commercializing 100% hydrogen power generation.

The procurement cost of hydrogen, meanwhile, is significant in commercializing hydrogen power generation. Specifically, the procurement cost of hydrogen, including the calculation of its environmental benefits, must be as competitive as that of other fuel sources in order to switch from conventional power generation to hydrogen power generation. The Basic Hydrogen Strategy stated that Japan aims to commercialize hydrogen power generation as well as the said international hydrogen supply chain technologies and cut the unit hydrogen power generation cost to 17 yen/kWh around 2030 and will aim to make hydrogen power generation (including the environmental value) as cost competitive as LNG power generation in the later future.

Description in the Basic Hydrogen Strategy (excerpts)

- Hydrogen can be used in conjunction with natural gas for power generation and will initially be used mainly for existing natural gas power plants and for small cogeneration systems to promote hydrogen diffusion.
- It is indispensable to develop combustors that are suitable to hydrogen's combustion characteristics. Research, development, and demonstration initiatives have been implemented for technologies to allow diffusive, premix, and other proven combustors for fossil power generation to be used for the mixed combustion of hydrogen and natural gas. In the future, technological challenges will be addressed to reduce NOx emissions and improve power generation efficiency. To realize hydrogen-only power generation, Japan will attempt to commercialize new combustion technologies to simultaneously achieve NOx reduction, higher generation efficiency, and high-density combustion of hydrogen and natural gas.
- Japan aims to commercialize hydrogen power generation as well as international hydrogen supply chains and cut the unit hydrogen power generation cost to 17 yen/kWh around 2030. To achieve this, Japan's annual hydrogen procurement may have to reach around 300,000 tons (amounting to 1 GW in power generation capacity). In the later future, Japan will aim to make hydrogen power generation (including the environmental value calculation) as cost competitive as LNG power generation. To this end, Japan's annual hydrogen procurement may have to increase to a total of 5-10 million tons (amounting to 15-30 GW in power generation capacity).
- For the introduction of hydrogen power generation, Japan will consider institutional designs that ensure hydrogen power generation's economic efficiency amid progress in electricity system reform. It is important to visualize the environmental value of hydrogen power generation in terms of assessment, certification and trading. While monitoring discussions on other institutional designs, Japan is considering clarifying the position of hydrogen use in the Energy Conservation

Act or positioning hydrogen power generation as a non-fossil power source in the Energy Supply Structure Sophistication Act.

Description in the fifth Strategic Energy Plan (excerpts)

- In tandem with the building of such supply chains, it is of importance for Japan to proceed with the development of a hydrogen power generation infrastructure that stably consumes a massive amount of hydrogen. Since the mixed combustion of hydrogen in natural gas-burning thermal power plants is possible, Japan will move to expand the introduction of hydrogen power generation, centering on efforts toward testing the mixed combustion at existing natural gas thermal power plants in the initial phase of the introduction, but also including the mixed combustion of hydrogen by small-scale privately-owned power generation facilities, and develop combustors suited to the combustion characteristics of hydrogen. Japan aims to commercialize hydrogen power generation as well as international hydrogen supply chains and cut the unit hydrogen power generation cost to 17 yen/kWh around 2030.

While key technologies such as combustors designed for hydrogen's combustion characteristics should be developed and the procurement cost of hydrogen should be reduced to commercialize hydrogen power generation, prospects for establishing hydrogen mixed power generation technology are emerging.

As a roadmap and an action plan, therefore, appropriate measures should be taken to design feasibility studies for identifying the conditions for introduction of hydrogen power generation, to determine the technological requirements for 100% hydrogen power generation and to set the cost of hydrogen including its calculated environmental value to compete against LNG thermal power generation. Specific measures include the following:

Road Map

- Japan will implement measures to pursue technological development and reduce the cost of hydrogen to allow for the commercialization of hydrogen power generation in around 2030.
- Japan will identify requirements for introducing co-combustion power generation using hydrogen into existing thermal power plants in around 2020.
- Japan will use the heat produced by gas turbine combined cycle (GTCC) power plants to promote dehydrogenation reactions, given that the use of waste heat is key to improving the efficiency and cost of the reactions when generating power from hydrogen extracted from organic hydrides and ammonia.
- Japan will establish system requirements for ammonia dehydrogenation by FY 2020.
- Japan will develop techniques to control NOx emissions without water injection to establish technologies for hydrogen co-generation systems, with the aim of achieving a power generation

efficiency of 27% (1 MW-class, terminal efficiency, LHV) and a NOx concentration of 35 ppm (converted into O2-16%) by FY 2020.

- Furthermore, in the future Japan will try to establish elemental technologies for 100% hydrogen power generation, while evaluating prospects for reducing procurement costs.
- Japan will try to reduce the cost of hydrogen (delivered from plants) to about 30 yen/Nm3 in around 2030 and to 20 yen/Nm3 thereafter in order to make hydrogen energy including its calculated environmental value as cost-competitive as conventional energy sources, taking into account LNG price trends. For example, an LNG price of $10/MMBtu (on CIF basis) corresponds to a hydrogen price of 13.3 yen/Nm3 (in terms of energy output, disregarding environmental benefits).【Repeated below as P5】(A hydrogen cost of 30 yen/Nm3, 20 yen/Nm3 and 13.3 yen/Nm3 corresponds respectively to 17 yen/kWh, 12 yen/kWh and 8.7 yen/kWh in terms of power generation unit price).

Action Plan

- Japan will conduct feasibility studies by FY 2019 on hydrogen supply systems, critical mixed-fuel burning ratio, economic viability, etc., in preparation for hydrogen-mixed combustion at existing thermal power plants, to identify requirements for introduction of co-combustion power generation using hydrogen.
- Japan will develop technologies for high-efficiency, low-cost processes using waste heat to dehydrogenate organic hydrides and ammonia. Japan will evaluate the durability of combustors and catalysts by FY 2020 for processing ammonia under normal pressure.
- Japan will develop techniques by FY 2020 to control NOx emissions without water injection to improve the efficiency of hydrogen co-generation systems.
- Japan will develop technologies to commercialize 100% hydrogen power generation such as Low NOx combustors, combustion vibration control, and cooling techniques, etc., based on prospects for reducing the procurement cost of hydrogen.
- Japan will implement measures required to fully commercialize hydrogen power generation upon completion of feasibility studies with promising results, taking into account developments in hydrogen supply chains and the procurement cost of hydrogen.

Supplement

Elemental technologies should be developed, and the procurement cost of hydrogen should be reduced to allow for the commercialization of hydrogen power generation in around 2030 according to the Basic Hydrogen Strategy.

While feasibility studies are underway for co-combustion power generation using hydrogen at existing thermal power plants, Japan will evaluate different variables and scenarios including critical co-combustion rates without retrofitting existing gas turbine combustors, the performance of hydrogen-mixed combustion (flame stability, flame temperature, NOx emissions, etc.), possible impacts on power generation and environmental performance, possible impacts of hydrogen-mixed combustion on existing facilities and the operation of power plants and the durability and reliability of the systems involved. Those studies also involve review of hydrogen supply systems (receiving, storing, supplying and mixing of hydrogen as well as the behavior of hydrogen in existing piping) and the basic design of hydrogen-mixed combustion systems in power plants, while requirements for introduction of co-combustion power generation using hydrogen will be identified and summarized in FY 2019.

It is also important to reduce CO_2 emissions from entire hydrogen supply chains from the perspective of decarbonization, which requires high-efficiency and low-cost processes. One effective solution is to use waste heat to reduce energy input from outside sources for dehydrogenation when generating power from hydrogen extracted from organic hydrides and ammonia, whose dehydrogenation is energy-intensive.

While techniques to control NOx emissions with water injection are being established for hydrogen co-generation systems, non-water-injection systems should also be developed to improve power generation efficiency.

As mentioned already, hydrogen power generation technologies for large-scale operations are nearing completion. The challenge then is to reduce the cost of hydrogen supply, which is being addressed – as described in Section 2-1. (1) Technological development for low-cost hydrogen procurement and supply – and the economic viability of hydrogen power generation should be reviewed in accordance with the technological development. In view of the above, the cost of hydrogen (i.e., the economic viability of hydrogen power generation) will be examined and reviewed, and measures for the full-scale introduction of hydrogen power generation will be discussed and carried out when it becomes economically feasible.

2-2. (2) Hydrogen use in mobility

CO_2 emissions from the transportation sector account for almost 20% of Japan's total CO_2 emissions, with about 85% of those originating from automobiles (cars and trucks). Low-carbon vehicles, trucks, busses, etc. should therefore be promoted to decarbonize the transportation sector.

As the energy density of hydrogen per unit weight/volume is larger than that of storage batteries (lithium-ion batteries, etc.), fuel-cell vehicles (FCVs) have a competitive edge over electric vehicles (EVs) when it comes to long-distance bus/truck transportation. Improvements expected in the power generation efficiency and fuel cell density, moreover, will likely lead to a longer transportation distance and a reduction in vehicle size.

In Japan, FCVs made their debut in December 2014, followed by the release of another model in March 2016. Japan, for that matter, is in the vanguard of FCV promotion, with 2,926 FCVs registered as of end-December 2018, one of the highest levels in the world.

At the same time, the construction of commercial hydrogen stations, which are key to promoting FCVs, began in FY 2013; 11 private-sector companies jointly set up Japan H_2 Mobility, LLC (JHyM) in February 2018 to develop hydrogen stations nationwide. Simulating the optimized locations of hydrogen stations based on the prospective promotion of FCVs, moreover, various players are stepping up efforts to effectively set up hydrogen stations while reducing the amount of upfront investment, which has resulted in the completion of 100 commercial stations (as of end-December 2018).

The Basic Hydrogen Strategy sets numerical targets for FCVs and hydrogen stations along with approaches to be adopted, considering that FCVs and hydrogen stations are indispensable in promoting hydrogen use in mobility.

Also important is to promote hydrogen use in other vehicles such as buses, forklifts and trucks – a prerequisite to the horizontal promotion of fuel cell technologies and increased utilization of hydrogen stations. Buses and forklifts powered by fuel cells already made their debut, while the private sector, domestic and international, plays a leading role in demonstrating and developing commercial fuel cell vehicles (trucks, etc.), and ships and trains. Indeed, fuel cell technologies are anticipated to have various applications.

Description in the Basic Hydrogen Strategy (excerpts)

- Japan aims to increase the number of FCVs in Japan to 40,000 units by 2020, to 200,000 units by 2025, and to 800,000 units by 2030. Japan also aims to expand the number of hydrogen stations in Japan to 160 by FY2020 and to 320 by FY2025 and make hydrogen stations independent by the second half of the 2020s.
- To achieve the abovementioned targets, reducing the supply costs of hydrogen (to make hydrogen as competitive as gasoline) will have to be combined with mass FCV production, FCV price reductions, further increases in driving distance of FCVs and the adoption of FCVs by the largest market segment around 2025, as well as the expansion of independent hydrogen sales businesses through hydrogen station development backed by stable profit and reduced development/operation costs. To this end, the government will promote regulatory reform, technological development, and cooperation with the private sector in the strategic development of hydrogen stations.
- FC buses launched regular services in 2017. Seeking to increase the number of FC buses including those for regular services to 100 by FY2020 and to 1,200 by FY2030, the government will consider wider use of FC buses in accordance with hydrogen station development and in cooperation with local governments.
- In Japan, large forklift users alone have the potential to buy more than 120,000 FC forklifts (consuming as much hydrogen as 360,000 FCV cars) and therefore have the potential of becoming a large hydrogen demand source. In Japan, FC forklift sales started in 2016. Toward their further diffusion, Japan will promote technological development to increase variation and capabilities, seeking to increase the number of FC forklifts in Japan to around 500 by FY2020 and to around 10,000 by FY2030.
- Commercial trucks number more than 3.2 million units in Japan, with greater potential to consume hydrogen than buses (230,000 units). Large FC trucks including distribution vehicles for

convenience stores have been analyzed in Japan and other countries. Based on the results, Japan will promote their technological development in an effort to diffuse FC trucks.

- While it is difficult to reduce CO2 emissions from ships in the mobility sector, fuel cells and other means of electrifying ships should be promoted to cut CO2 emissions. To this end, the government will draft safety guidelines for fuel cell ships in an effort to take advantage of the silent operation of fuel cell engines for introducing fuel cells first to small boats including pleasure craft, passenger boats and fishing boats. The government will also prepare a roadmap for expanding the use of fuel cells for ships, conduct demonstration tests based on the roadmap, and aim to disseminate FC ships preferentially beginning with the most cost-effective types of ships.
- As there is a wide range of applications for fuel cell technologies, expanding the current scope of applications is important for reducing environmental load and promoting mass production and cost reductions for fuel cells. Already, such fuel cell vehicles as garbage trucks, towing tractors and railway trains are in development and demonstration phases.

Description in the fifth Strategic Energy Plan (excerpts)

- It is important to push ahead with fuel cell vehicles (FCVs) and hydrogen stations, the two engines of hydrogen use in the mobility sector, as the two wheels of a vehicle. Specifically, Japan aims to construct hydrogen stations at 320 locations by 2025 and make the hydrogen station business self-reliant by the second half of the 2020s. As for FCVs, Japan aims to increase the number of FCVs in the country to 200,000 units by 2025, and to 800,000 units by 2030. Toward achieving the abovementioned targets, the reduction in the supply costs of hydrogen critically must be combined with mass FCV production, FCV price reductions, further increases in driving distance of FCVs and the introduction of FCV models for the volume market segment around 2025, as well as the expansion of independent hydrogen sales businesses through hydrogen station development backed by stable profit and reduced development/operation costs. To this end, the government will promote the "divine trinity" of regulatory reform, technology development and cooperation with the private sector in the strategic development of hydrogen stations.
- From the perspectives of the horizontal spread of fuel cell technology and the effective utilization of hydrogen station infrastructure, it is also important for Japan to go beyond already commercialized fuel cell buses and forklifts to promote the application of this technology to cover trucks and other commercial vehicles as well as ships and electric cars in the mobility sector. To that end, Japan aims to increase the number of fuel cell buses to around 1,200 units and the number of fuel cell forklifts to around 10,000 units by 2030.

With this direction in mind, as a roadmap and an action plan, the following summarizes 1) specifications of elemental technologies required to mass-produce low-cost FCVs and extend their driving range, along with a cost reduction breakdown, 2) the target costs for each component equipment necessary to reduce the maintenance and operational costs of hydrogen stations and 3) the target number of units for each means of mobility and approaches to achieving it.

(1) Fuel cell vehicles

Road Map

- Japan will try to introduce about 40,000 FCVs by 2020, 200,000 by 2025 and 800,000 by 2030.
- Japan will lower the price of FCVs to compete against HEVs (hybrid electric vehicles) in the same class. While there is a price gap of about 3 million yen between FCVs and HEVs, that between EVs and HEVs is about 700,000 yen[4] (with the former penetrating the market) – which is the target for what should be achieved for FCVs by around 2025 through technological development and promotional efforts based on public-private partnerships. The price gap between FCVs and HEVs in the same class, meanwhile, should be reduced to less than 1.8 million yen by around 2020.
- Japan will try to release new FCVs in 2025 with a focus on major market segments (SUVs, minivans, etc.), taking into account diversified consumer preferences, while introducing various models to expand sales channels and cut costs.
- The table below shows targets for technical specifications and costs with respect to fuel cell and hydrogen storage systems – i.e., elemental technologies for FCVs.

Target specifications	Present	Around 2020	Around 2025	Around 2030
Driving range	650km	⇒	⇒	800km
Maximum output density	3.0kW/L	4.0kW/L	5.0kW/L	6.0kW/L
Durability	15 years (passenger cars)	Over 15 years (passenger cars)	Over 15 years (passenger cars) 15 years (commercial cars)	Over 15 years (passenger cars) Over 15 years (commercial cars)
Amount of rare metals used	—	—	—	0.1g/kW
Hydrogen storage system (With 5 kg storage)	5.7wt%	6wt%	—	—

Cost & price levels	Present	Around 2020	Around 2025	Around 2030
Vehicle price (the Mirai class)	More than 7 million yen	—	Comparable to those of HEVs in the same class	—
FC system (fuel cell stacks)	About 20,000 yen/kW	< 8,000 yen/kW (<5,000 yen/kW)	< 5,000 yen/kW (< 3,000 yen/kW)	< 4,000 yen/kW (< 2,000 yen/kW)
Hydrogen storage system (With 5 kg storage)	About 700,000 yen *1	300,000 – 500,000 yen	< 300,000 yen	100,000 – 200,000 yen

*1 : Estimated by the Agency for Natural Resources and Energy based on published statistics

Action Plan

- For fuel cell systems, Japan will 1) develop technologies to reduce the thickness of electrolyte

[4] The price gap between the Nissan Leaf EV (40 kWh) and the Toyota Corolla Sport HV, both with similar specifications, with subsidies and tax breaks taken into account.

membranes, prevent cross leakage (where hydrogen fed to the fuel electrode and oxygen fed to the air electrode pass through the electrolyte membrane) and maintain/improve durability, and 2) maintain/improve the performance and durability of rare metal catalysts and develop technologies to reduce the use of rare metals or replace rare metal catalysts themselves – e.g., mass-production of core-shell catalysts and the use of catalysts with new structures (nano-wires, nano-sheets, etc.).

- For hydrogen storage systems, Japan will reduce the use of costly carbon fiber in vehicle hydrogen tanks and develop efficient winding techniques.
- Technical information and challenges in collaboration areas should be shared, while universities, research institutes and other concerned companies are expected to come up with solutions to establish a multi-layered technological development system based on cooperation among government, industry and academia.

Supplement

Despite Japan's auto industry's efforts to develop FCVs, only two auto makers have put them on the market, and they are priced higher than conventional and other next-generation vehicles in the same class. The target price has thus been set for FCVs in order to promote their sale, taking into account prospects for technological innovation and consumer preference. For example, the Toyota Mirai equipped with a navigation system is priced at about 7.6 million yen while the Toyota Crown Hybrid in the same class costs about 5 million yen; there is a price gap of about 2.6 million yen between the two. The current price level should be lowered by more than 800,000 yen in around 2020 and by about 1.1 million yen in around 2025 to narrow the effective price gap to less than 1.8 million yen in around 2020 and to about 700,000 yen in around 2025 (provided that the average price of HEVs remains the same and FCVs in the same class as the Toyota Crown HEV are on the market).

As for specifications required for FCV elemental technologies and target costs, electrolyte membranes initially account for a large part of the cost of the fuel cell system while rare metals as catalysts are expected to remain costly despite being mass-produced. Research and development should thus be conducted on these materials, coupled with the development of mass-production techniques.

Likewise, as for hydrogen storage systems, both reducing the use of costly carbon fiber in vehicle hydrogen tanks including by developing new materials, and developing mass-production techniques such as streamlining the winding process and shortening the resin curing time should advance.

It is important that developments in these elemental technologies and new models be monitored regularly, and the developments should be promoted by automakers through sharing of technical information and efforts in collaboration areas, and by concerned parties such as universities and research institutes through presenting proposals for solutions to existing problems – creating a multi-layered technological development system based on cooperation between government, industry and academia.

(2) Hydrogen stations

Road Map

- The vision for hydrogen stations is for the private and public sectors to work together to construct stations in 160 locations by FY2020, and 320 locations by FY2025, with a view to creating a self-reliant hydrogen station industry by the late 2020s.
- Around 500 yen/kg is the target average profit margin (gross margin[5]) from hydrogen sales by the late 2020s.
- The target for construction and operating costs of hydrogen stations has been set at half (construction cost: 230 million yen, operating cost: 23 million yen) of the costs in the early period around 2020, and significantly lower by 2025, when compared to the early period (construction cost: 200 million yen, operating cost: 15 million yen), with the target costs for each type of elemental technology as shown in the table below.
- Standardization and normalization will be achieved by setting industry-wide standards for each type of component by FY2020, with the aim of standardizing the specifications and control methods of components used at hydrogen stations.

	Initial rollout phase	2016	Around 2025
Compressor	140 million yen	90 million yen	50 million yen (100 units/year per company)
Pressure accumulator	50 million yen	50 million yen	10 million yen (500 units/year per company)
Pre-coolers	30 million yen	20 million yen	10 million yen (100 units/year per company)
Dispenser	60 million yen	20 million yen	20 million yen (100 units/year per company)
Other installation costs	180 million yen	170 million yen	110 million yen
Total construction costs	**460 million yen** →	**350 million yen** →	**200 million yen**
Operating costs	**40 to 50 million yen** →	**34 million yen** →	**15 million yen**

* Excerpts from technical development roadmap under compilation by NEDO.
* The prices for the initial rollout phase are average figures of grant applications in 2013, and the figures for 2016 are average figures for the actual amounts granted in 2016.
* The specifications of stations assume stationary off-site stations with a supply capacity of 300 Nm^3.
* Figures only include costs that are covered by grants.
* The target costs of components are based on a number of preset conditions, including revisions to regulations, mass-production of main components in accordance with reliable specifications, and appropriate balancing of delivery times following large-scale orders.
* The figures for XX units/year per company refers to preconditions for achieving the cost targets, implying the conditions "if one company produces XX

[5] The profits (gross margin) of hydrogen sales mentioned here refers to the gross margin on the unit sales of hydrogen, which only includes costs related to the procurement of hydrogen in the base cost (such as manufacturing and transportation) and does not factor in construction or operating costs.

number of units in one year."

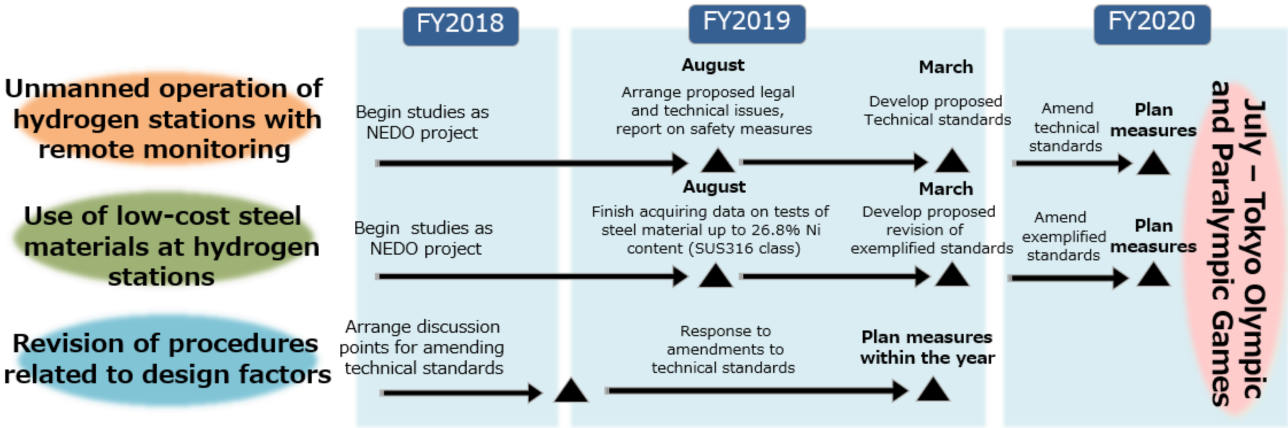
Action Plan

- Japan will expand the number of regions with hydrogen stations and discuss ways to construct a nationwide hydrogen station network from FY2019 onwards, with the goal of achieving faster uptake of fuel cell vehicles and a self-supporting hydrogen station industry. Japan H2 Mobility, LLC (JHyM) will play a central role in these measures, following the strategic milestones outlined below.
  - FY2018 to FY2021: Japan will aim for construction of hydrogen stations in a total of 80 locations, starting with the four major metropolitan areas in Japan, with a key focus on major cities and core transportation networks.
  - FY2022 to FY2025: Japan will review construction sites based on construction and other conditions studied in FY2021 while advancing construction of more hydrogen stations, with the aim of 320 locations by FY2025.
  - Japan will make construction of hydrogen stations more efficient, including utilizing existing mobile hydrogen stations in regions where no stations have been constructed, and using packaged hydrogen stations that are space- and cost-efficient and that help shorten construction times.
- Focusing on other areas aimed at making hydrogen stations more convenient for users as well as better defining the route for a self-supporting industry, Japan will implement measures to expand operating hours and remain open on weekends, or construct hydrogen stations at the same locations as existing gasoline stations or convenience stores.
- In addition to increasing the durability of sealing materials and hoses and developing next-generation filling technologies aimed at reducing the cost of hydrogen stations, Japan will focus development on technologies such as electrochemical compressors.

Item	Target	Effects of Cost Reduction
Increase durability of sealing materials and hoses	The durability of dispenser O-rings and other sealing materials is currently around 2,200 filling cycles, however the aim is to increase this to the following. ○ 15,000 cycles in 2020 ○ 30,000 cycles in 2022 The durability of hoses used for filling is also set to be improved.	Having to replace parts less frequently shortens the time required for regular maintenance, which is expected to reduce operating costs by 1 to 2 million yen per year.
Develop next-generation filling technologies	Develop next-generation filling technologies with a higher cooling temperature than the approx. -40°C currently required, without increasing the filling time above 3 minutes.	Cooling hydrogen currently requires approx. 4 million yen per year in electricity costs, however this is expected to decrease to around 3 million

	○ -25 to -33°C in 2020 ○ -15 to -25°C in 2022	yen in 2020, and around 2 million yen in 2022.

- To reduce the construction and operating costs of hydrogen stations, revisions will gradually be made to 37 items raised in the Regulatory Reform Implementation Plan (Cabinet Decision on June 9, 2017), while ensuring that safety is maintained. The timing of the objectives for the three key items below are set out in the following image.



- To achieve significant reductions in construction and operating costs of hydrogen stations, related industries will identify during FY2019 any regulatory issues that need to be resolved, examine how such issues are necessary and then develop appropriate plans of action, with safety as a primary consideration.
- Standardization and normalization will be achieved by closely studying methods of setting industry-wide standards for specifications and control methods of components used at hydrogen stations constructed by FY2020.

Supplement

Construction of commercial hydrogen stations began in FY2013, and currently 100 (as of the end of December 2018) hydrogen stations have been constructed mainly around the four major metropolitan areas in Japan. Achieving the objective of 160 stations in FY2020, 320 stations in FY2025 and a self-supporting hydrogen station industry by the late 2020s will require mass-production of fuel cell vehicles, lower costs and more models being made available to the largest market segments. An independent hydrogen marketing business will also need to be developed by reducing construction and operating costs for hydrogen stations, which is the key to reducing hydrogen procurement costs and ensuring stable profitability.

With this in mind, to efficiently and effectively generate maximum demand for fuel cell vehicles, the optimum locations of hydrogen stations will be determined mainly by JHyM. To expand the hydrogen station network so that it eventually spans the entire country, studies will be run from FY2019 with the goal of increasing the number of regions where construction is covered by the government subsidy system, eventually to cover all prefectures in Japan. Construction of hydrogen stations requires the understanding and cooperation of local municipalities where the stations are located, so initiatives will be run to increase understanding among residents and to make information on regulations and systems available. Other efforts will be made to encourage local governments to introduce support programs to increase sales of fuel cell vehicles. Additionally, mobile hydrogen stations constructed from FY2014 to FY2017 will gradually be switched over to permanent hydrogen stations in line with how popular fuel cell vehicles become in those particular regions, and mobile hydrogen stations that are no longer needed will be considered for use in different regions. Furthermore, space-efficient and low-cost packaged hydrogen stations (where main components such as the compressors, pressure accumulators and chilling units are installed within one or two cylinders) will be utilized wherever feasible as they are effective in shortening construction times.

Constructing hydrogen stations at the same locations as existing gasoline stations or convenience stores whose staff are able to also manage the hydrogen station in addition to currently existing facilities will lead to expanding operating hours and opening on weekends, and increase the convenience for FCV users.. This will also provide users access to services other than filling up with hydrogen, including other car maintenance services or convenience store purchases. The government subsidy system will also be developed with a management system that is designed to increase convenience, such as a framework that encourages expanding operating hours and opening on weekends.

Construction costs for hydrogen stations were around 350 million yen in FY2016, which is significantly higher than the costs required for the construction of ordinary gasoline stations at below 100 million yen. The operating costs of hydrogen stations were around 34 million yen/year as of 2016, compared to a lower cost of around 20 million yen/year for natural gas stations that deal with high-pressure gas, and it will be vital to approach the cost of such existing infrastructure as soon as possible.

In order to gradually achieve such cost reductions, setting targets and implementing efforts to reduce costs is an important step for clarifying the prospects of future cost breakdowns for each type of component. With this in mind, this roadmap highlights the cost targets for around 2025 for compressors, pressure accumulators, pre-coolers, dispensers and other installation costs.

Reductions in costs can also be achieved by reviewing security regulations related to hydrogen stations, while ensuring that safety is maintained. For example, labor costs account for around 35% of the operating costs of hydrogen stations, however if unmanned operation of hydrogen stations can be approved with the use of remote monitoring as in cases overseas, significant reductions in labor costs are possible. Longer operating hours or an increase in the number of days that stations are open will also increase convenience for users of fuel cell vehicles. Out of the three key areas of the Regulatory

Reform Implementation Plan, the legal and technical issues as well as safety measures required for unmanned operation of hydrogen stations with the use of remote monitoring will be identified by August 2019, with the aim of having unmanned hydrogen stations in operation by the Tokyo Olympic and Paralympic Games in July 2020. Steel material used for hydrogen stations is currently produced in small lots at a high price, however data on how such material affects hydrogen will be acquired systematically with the aim of being able to use cheaper, ordinary materials by the Tokyo Olympic and Paralympic Games in July 2020. Equipment manufactured with a safety factor of 2.4 to comply with individual safety assessments overseas require individual safety assessments as well as special approval for use in Japan, however a framework will be developed during 2019 that eliminates the need for such special approval, hastening the overall process.

In addition to the above, revisions will steadily be made to regulations under the 37 items raised in the Regulatory Implementation Action Plan, and measures need to be continually implemented for any issues with potential new systems that may arise following the increased uptake of fuel cell vehicles and hydrogen stations. Initiatives will also be implemented to roll out the improvements required to make corrections to the way the High Pressure Gas Safety Act is applied by local governments. The various costs associated with hydrogen stations will be reduced with these measures.

Reductions in costs can also be expected with the standardization and normalization of hydrogen stations. Components used in current hydrogen stations are produced with different control programs, interfaces, specifications or other systems by each manufacturer or business operator, which results in higher construction costs as designs need to be adjusted accordingly for each construction. To resolve such issues, the goal is to set industry-wide standards for each type of component used at hydrogen stations by FY2020. In addition to reducing construction costs with fewer design adjustments by adopting industry-wide standards, another potential advantage is the entry of new component manufacturers from Japan and overseas.

(3) Other types of mobility

Road Map

- The target for the number of fuel cell buses has been set at 100 buses by FY2020, and 1,200 buses by FY2030. Buses are currently being increasingly used in metropolitan areas, however the uptake of such buses will be expanded throughout Japan in order to achieve this target.
- Price reduction of fuel cell buses will occur in line with the increase in performance of fuel cell stacks and fuel cell vehicles. The objective is to reduce the price of vehicles to around half of the current level by around 2023 to 2024[6] with sufficient performance as a zero emissions vehicle to compete against electric and other forms of buses, and to achieve a price point by around 2030 for self-sustaining business operation.

[6] The current vehicle price of a Toyota SORA is 105 million yen.

- The target for the number of fuel cell forklifts has been set at 500 forklifts by FY2020, with 10,000 introduced by FY2030. Models will be released in overseas markets such as North America where such models are already increasing in popularity.
- With regard to fuel cell trucks, Japanese manufacturers are already advancing demonstration projects for small trucks, while technical development and issues related to large trucks designed for short ranges (around 200 km, high-pressure gas tanks) and long-haul ranges (around 500 km, liquid hydrogen tanks) are being arranged with the goal of creating a concrete action plan by FY2020.
- With regards to hydrogen fuel cell ships, guidelines aimed at increasing the use of hydrogen in the marine industry will be developed by 2020.

Action Plan

- For fuel cell buses: Japan will (1) reduce the vehicle price (2) develop technologies for increasing fuel efficiency to reduce running costs (3) develop technologies for improving durability to reduce maintenance costs. Additionally, Japan will (4) develop models for purposes other than the current route buses in order to increase uptake. Further, (5) Fuel cell buses have a superior power supply capability, so Japan will develop measures required to utilize buses as a source of power in the event of disasters in less urban areas.
- Japan will steadily expand construction of hydrogen stations that can be used by fuel cell buses to increase the uptake of fuel cell buses.
- Japan will expand the number of models of fuel cell forklifts and develop fuel cell units that can be used in applications other than forklifts, to help reduce costs through economies of scale. Hydrogen refilling facilities for forklifts need to be constructed by logistics companies, so infrastructure companies and manufacturers will develop the measures required to construct simplified refilling facilities that are easy to operate.

Supplement

Fuel cell buses started being used for public transportation in March 2017, and there are currently 18 buses (as of the end of February 2019) operating as route buses in metropolitan areas. The Tokyo Olympic and Paralympic Games is deemed an ideal opportunity to demonstrate to the world the capabilities of Japanese hydrogen application technologies through the use of fuel cell buses by countless tourists. Fuel cell buses require more fuel compared to private fuel cell vehicles and usually travel similar distances on both weekdays and weekends, which is expected to result in stable demand for a large quantity of hydrogen and thus contribute to the stable operation of hydrogen stations. To increase the uptake of such buses into the future, automotive manufacturers and local municipalities need to work together to deploy buses for public transportation around the country, as well as develop models other than public transportation models to help reduce costs. Technical development is also required to improve fuel efficiency and durability in order to reduce vehicle prices as new models are released. Large-scale power outages following the Great East Japan Earthquake in March 2011 and the Hokkaido Eastern Iburi Earthquake in September 2018 resulted in greater awareness of disasters in regional areas. Fuel cell buses have a superior power supply capability, and can potentially be used as emergency power sources in the event of disasters in non-urban regions.

Fuel cell forklifts were first released in Japan in 2016, and around 150 units (as of the end of February 2019) have been deployed in areas such as airports and wholesale markets. There is currently only one model of fuel cell forklift available, however expanding the available range to include smaller and larger models will be vital for increasing their uptake. Expanding the number of use applications (such as stationary power generators or in agricultural and construction machinery) for fuel cell units installed in forklifts will be the key to reducing costs, due to the economics of scale that will come into play through the effects of mass-production. Hydrogen refilling facilities for forklifts also need to be constructed by logistics companies, however as these companies may not necessarily have the know-how required for such infrastructure, it will be important to work with infrastructure companies to develop measures for constructing simplified refilling facilities that are easy to operate.

Technical development of fuel cell trucks is progressing both in Japan and overseas. In Japan, two compact fuel cell trucks used for deliveries to convenience stores will be released in spring 2019 to begin demonstration tests. Japanese manufacturers are involved in technical development of large fuel cell trucks both in Japan and overseas, and clear strategies will be required for releasing such models globally.

With regards to hydrogen fuel cell ships, a field test of a small fuel cell-powered boat was conducted from the end of FY2016 with the aim of identifying any technical issues, the results of which were used to develop "Safety Guidelines for Hydrogen Fuel Cell Ships" at the end of FY2017. In addition to fuel cells, there is the potential of using hydrogen gas engines as a source of ship propulsion, so the need for technical development and other issues should be examined while keeping an eye on international trends. These conditions shall be used as the basis for developing guidelines aimed at increasing the use of hydrogen in marine industry by 2020.

In other mobility fields, fuel cell vehicles including garbage trucks, towing tractors and rolling stock are already in the development and demonstration phases. For rolling stock, railway companies and automotive manufacturers are already working together on initiatives aimed at developing a hydrogen supply chain located around train stations. There is also a high level of anticipation for hydrogen and fuel cells to be used for mobility in the space field, and studies are already underway in the world's first use of fuel cells as the power source for a manned rover (manned pressurized rover)[7] to explore the moon's surface. Advanced mobility technology such as this is vital for carving a path to a “hydrogen society.” Adopting common specifications for fuel cell modules will be an effective way of increasing use applications across a broad range of fields.

[7] A vehicle that can be used for sustained travel across the surface of the moon or other celestial body, without the need for astronauts to wear spacesuits.

2-2. (3) Potential use of hydrogen in industrial processes and heat utilization

Fossil resources such as oil and natural gas, as well as petroleum products and plastic products made from these resources, are all essentially hydrocarbons that primarily consist of carbon and hydrogen. During their manufacturing process, hydrogen is used as a resource that is produced or recovered as a by-product, including hydrogen produced as a by-product during the decomposition process of high molecular weight hydrocarbons, or hydrogen added to hydrocarbons to synthesize different types of hydrocarbons. During the steelmaking process, coke (coal) that is used as a reducing agent for iron ore is also a hydrocarbon that mainly consists of carbon and hydrogen, and hydrogen is produced as a by-product of coke decomposition. Steel refineries also use hydrogen as a reducing agent during the surface treatment process of steel products such as stainless steel. Hydrogen is produced, recovered or used as a resource in a similar way in a broad range of industries, and if economically feasible, such industrial processes have the potential as a hydrogen supply source or utilization as part of the future hydrogen supply chain outlined in policies such as the Basic Hydrogen Strategy or the 5th Basic Energy Plan.

There are many examples of industrial processes that are a hydrogen supply source, including recovering by-product hydrogen produced at oil or steel refineries and utilizing it as heat in the form of fuel for other boilers at the same processing plant, or using the hydrogen as a resource for different processes at the same processing plant. By-product hydrogen produced during the manufacturing process of caustic soda has a high level of purity, which is then on-sold as hydrogen.

Industrial processes that use hydrogen are likely to represent low-carbon versions of those industrial processes. For example, low-carbon efforts are being implemented throughout industries in Europe, with trial calculations estimating that by 2030, hydrogen produced from renewable energy in these industries will fulfill 17% of the total demand for hydrogen. Examples of the use of hydrogen produced from renewable energy sources in low-carbon steelmaking processes include the HYBRIT project (Sweden) and the H2FUTURE project (Austria). In Japan, the COURSE50 project is underway with the aim of reducing CO2 emissions in the steelmaking process. Such technical development involving iron ore reduction using hydrogen-rich coke oven gas aims to cut total CO2 emissions at steel mills by 30%, based on the assumption of maximum utilization of the existing infrastructure. Development of hydrogen utilization technology and CO2 separation and recovery technology utilizing unused waste heat is progressing with the aim of making the first commercial refinery operational in 2030. Further into the future, hydrogen reduction steelmaking technology will be developed with the aim of achieving zero emissions during the steelmaking process. The COURSE50 project is technology that utilizes by-product hydrogen from steel mills, however more advanced hydrogen reduction steelmaking technology is based on the assumption that hydrogen will be procured from external sources in addition to the refinery's by-product hydrogen. While steel mills are a source of hydrogen today, they may potentially be an area where hydrogen is utilized in the future.

In light of this information, there are high hopes that the utilization of hydrogen in industrial processes will help achieve a low-carbon industry, and there is the potential for such processes to become a vital area of hydrogen utilization on the path to a "hydrogen society."

Description in the Basic Hydrogen Strategy (excerpts)

- CO2-free hydrogen, which is set for massive procurement and consumption in or after 2030 could be used not only in power generation and mobility sectors but also in the industrial sector to reduce carbon emissions in energy areas where electrification is difficult.
- Hydrogen now used for such industrial processes as steelmaking and oil refining is produced from fossil fuels and could be replaced with CO2-free hydrogen to reduce CO2 emissions.
- Europe is considering utilizing "Green Hydrogen" in industry and other sectors... In a bid to substantially reduce CO2 emissions in the steelmaking process, Europe is also considering substituting natural gas used as reductant for the direct reduction ironmaking process with renewable-based hydrogen.

Both the supply and use of hydrogen have the potential to be adopted as practices in industrial fields as long as economic viability can be achieved. In addition to fields such as mobility and power generation, industrial fields are an important target for measures to promote hydrogen use, as they can reduce the costs associated with hydrogen use through economies of scale. Below are a road map and action plan based on the direction indicated in the Basic Hydrogen Strategy. These contain targets for the use of CO2-free hydrogen in industrial fields and initiatives that should be carried out to achieve those targets.

Road Map

- Japan will aim for CO2-free hydrogen to be used in industrial fields in the future, while following system designs that have been planned for the future based on hydrogen's calculated environmental value.
- 30 yen/Nm3 has been set as a target for the cost of hydrogen (plant delivery) to be achieved by around 2030, with plans to further reduce costs to around 20 yen/Nm3 in future. With that said, economic viability will differ for each industrial process as the existing fuel that would be replaced by CO2-free hydrogen differs (some processes use fossil fuels while others use hydrogen derived from non-CCS fossil fuels), as do the related costs. Discussions about switching to CO2-free hydrogen should therefore start with processes that are likely to be most economically viable.

Action Plan

- Japan will carry out a survey to determine the potential for hydrogen supply capability using domestic byproduct hydrogen or other unused resources (see above).
- Thoroughly investigate the requirements for using CO2-free hydrogen in each industrial process, including technical requirements such as purity, and the level of difficulty involved in receiving CO2-free hydrogen and the level of difficulty of the electrification of the process, and pricing conditions that must be met to ensure economic viability. After this, conduct an investigation to evaluate the potential of using CO2-free hydrogen.
- Conduct discussions and research to combat climate change by recycling carbon with carbon capture and utilization (CCU) technology, such as technology that can make products such as plastic products from CO2-free hydrogen and carbon dioxide.

Supplement

When discussing the procurement cost of hydrogen, it is important to consider that the type of fuel that can be replaced with CO2-free hydrogen depends on the industrial process, as do the costs involved. For example, a report distributed at the 10th Working Group for CO_2-free hydrogen on October 2, 2017 indicated that there is a range of costs (from 23-37 yen/Nm3) to produce hydrogen for the purpose of oil refinement processes.

The most effective way to handle this will be to carefully investigate the technical and economic conditions for the use of CO2-free hydrogen in each industrial process, evaluate the potential and then start with discussions about implementing CO2-free hydrogen in the fields where it will be the most economically viable.

A technology has been developed that synthesizes materials such as methanol from hydrogen and carbon dioxide, as a carbon recycling system utilizing CCU technology. More efficient, lower cost technology is expected to be developed in the future, and the use of this technology in industrial fields is expected to reduce carbon dioxide emissions.

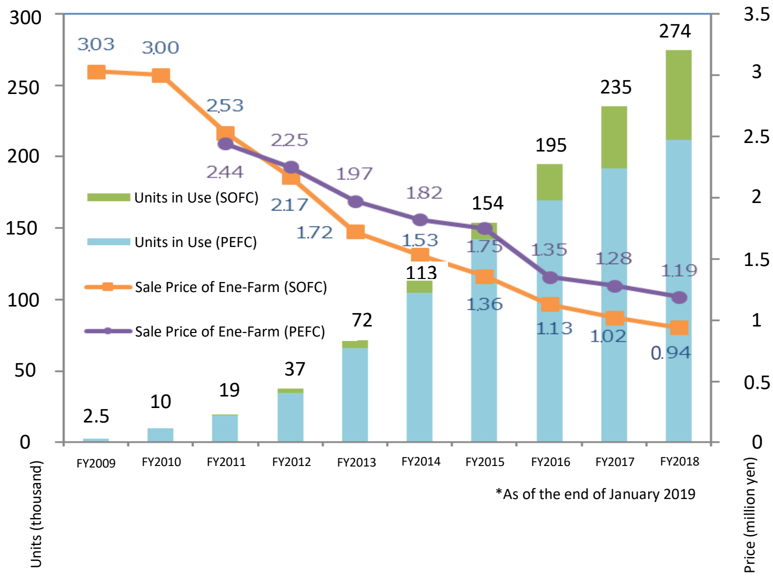
2-2. (4) Utilizing fuel cell technologies

Fuel cells are one of the most important forms of technology for hydrogen use. Electricity and heat is generated through an electrochemical reaction, which has three benefits: (1) highly efficient generation, (2) compact equipment and (3) effective use of waste heat.

Small-scale distributed power supplies using fuel cells have the potential for rapid popularization as a distributed power supply as they can generate power about as efficiently as large-scale thermal power plants, without requiring the large investment that is needed for power plants of that nature. They are also expected to be used as VPPs as IoT is adopted in the future, and will also be effective for BLCPs (business and lifestyle continuity plans) as they can be started and run independently in the event of a power outage.

Japan responded to these circumstances by being the first country in the world to market household fuel cells (Ene-Farm) in 2009. Around 274,000 Ene-Farm cells are in use as of the end of January 2019.

Strong progress has also been seen in the commercial and industrial sectors, with a full-scale launch of Japanese-made fuel cells (SOFC cells) in these markets in 2017. Discussions are taking place about the possibility of installing pure hydrogen fuel cells in the Olympic and Paralympic Villages of the 2020 Olympics and Paralympics in Tokyo.



Source: Created by the Agency for Natural Resources and Energy

Description in the Basic Hydrogen Strategy (excerpts)

- To give Ene-Farms economic advantages over traditional residential energy systems, Japan will attempt to lower the price to 800,000 yen for a standard polymer electrolyte fuel cell (PEFC) and to 1 million yen for a standard oxide fuel cell (SOFC) (to shorten the investment recovery period to seven to eight years) by around 2020 to secure their later autonomous diffusion. Japan will also aim to shorten the investment recovery period to five years by around 2030 by promoting initiatives that contribute to improving the advantages available to users.
- To this end, Japan will encourage technological development to further improve power generation efficiency for the SOFC and the fuel heat utilization factor for the PEFC and will explore advantageous markets, including residential buildings, cold regions, and Europe and other regions with high heat demand, to promote CO2 emission reduction in the building sector. Japan will also expand initiatives to promote trading in surplus electricity to provide efficiently generated surplus electricity to users plagued with power shortages.
- Japan will promote the introduction of commercial and industrial fuel cells with low heat-to-power ratios and step up technological development to reduce initial costs to allow fuel cell costs to fall below the grid parity as soon as possible. Japan will also promote technological development to increase the fuel cell power generation efficiency above 60% for sophisticated, gas-turbine-combined-cycle (GTCC) power plants, exploring the feasibility of supplying power through "dispersed power sources."

- As the supply of renewable energy is expected to increase in Japan with international hydrogen supply chains developed from 2030, Japan will aim to spread pure hydrogen fuel cell co-generation systems using CO2-free hydrogen.

Description in the fifth Strategic Energy Plan (excerpts)

- At present, the most prevalent hydrogen-related technology is household fuel cells (Ene-Farm). Particularly, with the technological advantages of fuel cells, stationary fuel cells were introduced into average households in Japan ahead of other countries, with over 230,000 units of such fuel cells already in use. The current price is below 1 million yen, less than one third of the initial market price.
- Going forward, Japan will aim for the introduction of 5.3 million units by 2030 after achieving a self-sustaining market by around 2020. In order to approach the realization of that goal, Japan will develop technologies for further improvement of power generation efficiency and higher heat utilization, cultivate particularly suitable markets, such as regions with large thermal demand, and further expand efforts to make power available to other consumers through surplus power trading.
- In addition, for the diffusion of fuel cells for business and industrial use brought onto the market in 2017, Japan will go ahead with the development of technology conducive to initial cost reductions to make that market self-sustaining at an early date, and push for the development and actual use of equipment that has a power generation efficiency of 60% as a dispersion-type power source, higher than that of the large-scale, concentrated power source.

While distributed power supplies using fuel cells generate power efficiently and use both electricity and heat effectively, the initial cost and running benefits are not currently attractive enough to potential users. To further popularize 1) household fuel cells (Ene-Farm) and 2) fuel cells for commercial and industrial purposes, costs need to decrease and functionality needs to increase. Below are a road map and an action plan containing the targets that need to be achieved and the measures that should be implemented for this purpose.

(1) Household Fuel Cells (Ene-Farm)

Road Map

- Japan will achieve a self-sustaining market for Ene-Farm by around 2020 and increase the number of cells in use to 5.3 million units by 2030.
- Japan will reduce the price of standard PEFCs (polymer electrolyte fuel cells) to 800,000 yen and the price of standard SOFCs (solid oxide fuel cells) to 1,000,000 yen (and thus shorten the return on investment period to seven to eight years) by around 2020 and promote future independent popularization. After this, continue carrying out initiatives to invest in the improvement of other benefits to users, with the aim of reducing the return on investment period to five years by around 2030.

Action Plan

- Japan will work to steadily decrease the price of Ene-Farm by carrying out technical development to enable increasingly compact devices, such as the development of more efficient cell stacks, and revise the stack structure and auxiliary machinery parts to make the system smaller and simpler.
- Japan will work to achieve full-scale popularization of Ene-Farm by exploring markets such as existing homes, residential buildings, cold regions and regions using LP gas. Measures to achieve this include commercializing compact, easy-to-install devices, developing and launching products with specifications suited to the energy consumption of residential buildings, reducing the cost of devices designed for cold environments, developing technology to reduce the cost of desulfurization equipment and expanding sales channels.
- Japan will reduce the material and construction costs associated with installation work by making devices more compact and fundamentally simplifying them as a result. Consider establishing regulations for the simplification of electrical work.
- To aid in full-scale popularization of Ene-Farms, Japan will expand the framework for collaboration and cooperation between parties such as gas companies, device manufacturers, home construction companies and developers to a national level by FY2019.

Supplement

The initial cost (including installation cost) of household fuel cells (Ene-Farm) has decreased from 3 million yen when Ene-Farm was first launched in 2009 to around 950,000 yen for the PEFC type at present, and this cost is gradually decreasing with each new model. Further cost reductions are needed with future model changes, and installation needs to be made easier so that Ene-Farm can be popularized on a larger scale.

The measures concerning equipment, maintenance and installation costs in the table below are to be carried out in future to steadily reduce costs. For example, cell stack costs are to be reduced by carrying out technological development to increase efficiency and decrease material costs, while also facilitating expansion of cell stack suppliers and stimulating competition between suppliers as a result. Auxiliary machinery costs are also to be reduced through measures such as changing the basic design to combine and eliminate parts, adopting less costly materials and structures and reviewing suppliers. Additionally, costs for processes such as installation and maintenance are to be reduced by modifying construction sites to reduce the amount of equipment such as cables and electric wires that are needed and carry out fundamental simplification to reduce base material and work costs, as well as revising maintenance methods such as how maintenance networks are used. Costs for electrical work are to be reduced by establishing regulations to improve the electrical specifications. At present, fuel cells have three-wire connections and an output of 200V, and therefore require contracting an electrician and interior remodeling or renovation work. The proposed regulations would enable two-wire connections and an output of 100V, eliminating the need for interior work.

In addition to these measures to be taken by individual businesses, full-scale popularization of Ene-Farm will require all relevant businesses to work together. The framework for collaboration and cooperation between parties such as gas companies, device manufacturers, home construction companies and developers is therefore slated for expansion to a national level.

Large category	Medium category	Small category	Item
Devices (costs)	Stack	Reduction of quantity of cells in stack	Revise and simplify cell stack structure (reduce quantity of cells and increase efficiency of each cell)
		Revision of cell stack materials	Reduce quantity of separators through use of new technology; adopt new low-cost materials, electrolytes, etc.; adopt new suppliers; adopt high-performance stacks
		Reduction of quantity of catalysts used in fuel cells	Develop new catalysts to reduce quantity of platinum used and improve activity of catalysts
		Expansion of cell stack suppliers	Currently only one supplier of SOFC cell stacks →Increase suppliers through technological development support, etc., and stimulate competition to drive prices down
	Auxiliary machinery (structural parts)	Reduction of quantity of auxiliary equipment parts	Change basic design to reduce quantity of auxiliary equipment parts by eliminating, merging, integrating with adjacent parts, changing desulfurization method, etc.
		Adoption of low-cost auxiliary equipment	Reduce costs by adopting new parts, methods, structures and suppliers
		Expansion of suppliers of parts, materials, etc.	Adopt new suppliers, including for group companies
	Fuel processing equipment	Simplification of reformers and hot modules	Reduce welded areas, revise housing structure, improve welding method, etc.
	Hot water tank	Standardization of communication with fuel cell bodies	Standardize communication to enable adoption of hot water tanks from various suppliers
		Revision and simplification of hot water tank specifications	Integrate hot water tank unit with fuel cell unit
	Controls	Reduction of base size	Reduce size and number of layers of substrate through measures such as development of dedicated IC
Devices (other)	Maintenance	Revision of parts to eliminate need for periodic replacement	Reduce frequency of maintenance that is required and eliminate the need for replacement of parts
		Use of networks for more efficient operations	Adopt network for remote management, expand from FY2016 → Use advance fault diagnostics to reduce number of visits required, reducing labor costs
	Expansion of sales channels	Expansion of range	Expand range according to market needs, expand from FY2017 (expand product range, develop compact devices, etc.)
		Use of existing maintenance frameworks	Build framework using existing service network
	Production processes	Improvement of production processes	Improve mass production method, adopt facilities for automation, improve yield → Decrease labor hours by up to 40% by around 2020
Installation	Test runs	Shortening and simplification of test operation time	Simplification of test operations, remote test operation, etc. → Reduce test operation time by up to 50%
	Structure of cables, electric wires, etc.	Simplification of cables, electric wires, etc.	Modify construction sites to reduce length and number of wires needed
	Base	Simplification of bases	Simplify bases by reducing size and lowering center of gravity of devices → Reduce material and construction costs of bases

At present, Ene-Farm is primarily being popularized in new detached houses being built on urban gas networks in the Kanto region and further south. In order to achieve full-scale popularization, additional markets such as existing homes, residential buildings, cold regions and regions using LP gas need to be explored.

Entry into the market for existing homes will require initiatives such as commercializing compact devices that are easy to install and creating a model with two-wire connections and an output of 100V as soon as possible to eliminate the need for interior electrical work. Approaching the residential building market will require the commercialization of compact devices, along with the development and launch of products with specifications suited to energy consumption in apartment buildings. In order to expand into cold regions, manufacturers will need to guarantee that the devices will work in cold environments through measures such as building support frameworks for installation and related work. The large amount of heat necessary to accommodate heated floors etc., needs to be met, and device costs need to be steadily decreased. Approaches for regions using LP gas include technological development to reduce the cost of the desulfurization equipment used to remove the sulfur component of LP gas and expansion of sales channels through the use of existing sales and distribution channels for high-efficiency water heaters.

(2) Fuel Cells for Commercial and Industrial Purposes

Road Map

- Japan has the following targets for system prices[8] and generation costs for fuel cells for commercial and industrial purposes and aims to achieve grid parity as soon as possible, including for waste heat management.

Type of fuel cells for commercial and industrial purposes	Around 2025	
	System price	Generation cost
Low voltage (several kW to several tens of kW)	500,000 yen/kW	25 yen/kWh
High voltage (several tens of kW to several hundred kW)	300,000 yen/kW	17 yen/kWh

- Japan aims to increase power generation efficiency to over 55% (net thermal efficiency and LHV) by around 2025 through technological development of elements such as the cell stack. An additional goal is to increase durability from the current life of around 90,000 hours to around 130,000 hours by around 2025. After this, aim to increase power generation efficiency to over 65% (net thermal efficiency and LHV) for the next generation of fuel cells for commercial and industrial purposes.

Action Plan

- Japan will decrease initial costs through the following measures: Japan will 1) undertake technological development to increase efficiency, output and density of the cell stack to decrease costs of cell stacks and fuel processors, 2) decrease the costs of auxiliary equipment by decreasing the number of parts used (blowers, flow meters, valves, heat exchange devices, etc.) or revising the specifications of expensive parts that could be replaced with lower-priced generic parts, and 3) decrease the costs of fuel cell systems through measures such as technological development and re-design to improve the part-load efficiency and load following functionality and simplify the component parts.
- Japan will improve durability by investigating the mechanisms by which elements such as the cell stack deteriorate and carrying out technological development to mitigate deterioration.
- Japan will carry out technological development for the next generation of fuel cells for commercial and industrial purposes to achieve power generation efficiency of over 65% (net thermal efficiency and LHV), surpassing the power generation efficiency of the latest gas turbine combined cycles (GTCC).

[8] Including price of device and installation costs.

Supplement

As fuel cells for commercial and industrial purposes generate power more efficiently and produce less waste heat than existing cogeneration systems, they are expected to be adopted in areas with a high demand for electricity and a low demand for heat (areas requiring a low heat to power ratio.) However, it is essential to improve the economics of the systems as the current initial costs make the systems less attractive to users than existing systems such as cogeneration systems, despite the efficiency and other benefits.

A calculation assuming that a low-voltage fuel cell system for commercial and industrial purposes currently has a price of around 1.8 million yen per kW, a life of 10 years and a fuel cost of 95 yen/Nm3[9], produces a generation cost of 50 yen/kWh, or around twice that of electricity from the grid (around 24 yen), and even the use of waste heat does not sufficiently improve the economic value. Meanwhile, for high-voltage fuel cell systems for commercial and industrial purposes, a calculation assuming that a high-voltage system has a price of 1.7 million yen per kW, a life of 10 years and a fuel cost of 73 yen/Nm3[10] produces a generation cost of around 40 yen – around 2.3 times that of electricity from the grid (around 17 yen), and again, the use of waste heat does not sufficiently improve the economic value.

This highlights the need to decrease costs to around the same price as electricity from the grid and achieve grid parity, as well as promoting independent popularization, all while taking into account additional value such as the use of waste heat and the benefits for BLCPs (business and lifestyle continuity plans). For this reason, manufacturers of low-voltage fuel cells for commercial and industrial purposes should aim to reduce generation costs to 25 yen/kWh by 2025. To achieve this, 500,000 yen/kW has been set as a target price for systems by 2025. For high-voltage fuel cells for commercial and industrial purposes, 17 yen/kWh has been set as the target for 2025, and 300,000 yen/kW has been set as the target generation price for systems by 2025.

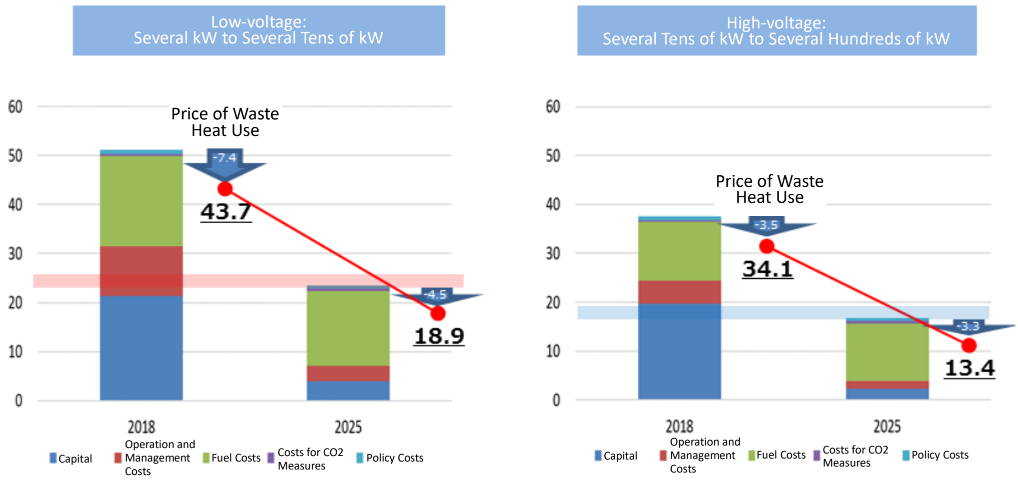
Measures to reduce these costs will mainly consist of technological development to reduce initial costs. As the cell stack and fuel processor account for around 60% of the initial cost and auxiliary equipment accounts for around 20%, initiatives will focus on technological development and building of systems for these components. Specific initiatives for the cell stack and fuel processor will include technological development for purposes such as increasing the efficiency, output and density of the cell stack and measures to increase net thermal efficiency (LHV) to 55% or more by around 2025. The costs of auxiliary machinery will be reduced by decreasing the number of parts for auxiliary equipment (blowers, flow meters, valves, heat exchange devices, etc.) or revising the specifications so that expensive parts can be replaced with lower-priced generic parts. The costs of fuel cell systems will be reduced through measures such as technological development and design to improve the part-load

9 Low-voltage systems have a fuel price of 95 yen /Nm^3 and a capacity factor of 95%.

10 High-voltage systems have a fuel price of 73 yen/Nm^3 and a capacity factor of 95%.

efficiency and load following and simplify the component parts. Additionally, a target has been set to increase the product lifespan from its current length of around 90,000 hours (around 10 years) to around 130,000 hours (around 15 years) by 2025.

In addition to these cost-reduction efforts, technological development will be carried out to achieve greater generation efficiency than large-scale concentrated power supplies (over 65%, net thermal efficiency, LHV).



Source: Created by the Agency for Natural Resources and Energy from the NEDO Technological Development Roadmap etc.

2-3. Promotion of technological development and understanding of these initiatives among Japanese people

2-3. (1) Development of innovative technology

The National Energy and Environment Strategy for Technological Innovation towards 2050 (NESTI2050) was decided by the Council for Science, Technology and Innovation in April 2016, and identifies promising technical fields for drastic reduction of greenhouse gas emissions by around 2050 based on global carbon reduction initiatives such as the Paris Agreement. The production, transportation, storage and use of energy carriers such as hydrogen are stipulated in NESTI2050 as technologies whose improvement should be prioritized and focused on.

Based on this, the Basic Hydrogen Strategy indicates the directions to be taken in the development of innovative technology to produce, transport, store and use hydrogen with the medium- to long-term aim of building a "hydrogen society" and achieving full-scale use of hydrogen by 2050. The Integrated Innovation Strategy (decided at a Cabinet meeting in June 2018) also states that it is important for industry, academia and government to work together on initiatives to build a world-leading "hydrogen society," from research and development of relevant technology to public implementation of that technology.

Description in the Basic Hydrogen Strategy (excerpts)

- To realize a hydrogen-based society and diffuse hydrogen use fully over the medium to long term through 2050, Japan will have to steadily develop innovative technologies for producing, transporting, storing and using hydrogen as follows:
- ✓ new hydrogen production technologies including highly efficient water electrolysis, artificial photosynthesis and hydrogen-permeable membranes to purify hydrogen
- ✓ highly efficient hydrogen liquefiers and long-lived liquefied hydrogen retention materials
- ✓ low-cost, highly efficient energy carriers
- ✓ technologies for compact, highly efficient, highly reliable and low-cost fuel cells
- ✓ innovative chemical synthesis methods using hydrogen and CO2

While medium- to long-term technological development will take some time before coming to fruition, initiatives need to be started with the future in mind. Various matters need to be assessed from the basic research stage onward, such as the prospects for cost reduction that will be essential for public adoption of the technology, the potential for large-scale implementation, and the compatibility with existing infrastructure, based on a future vision for society that combines environmental conservation with economic growth. As medium- to long-term technological development proceeds, it will be important to regularly discuss the current status and future development of the work. The following action plan provides specific details on the main innovative technology that needs to be developed based on the directions to be taken.

Action Plan

[Production]

- Research on new hydrogen production technology such as highly efficient water electrolysis, artificial photosynthesis and permeable membranes that will improve the purity of hydrogen
  - – Hydrogen production with catalysts containing zero or significantly lower quantities of rare metals, allowing for water electrolysis at lower temperatures and pressures.
  - – High-temperature water vapor electrolysis (SOEC[11]) that, in principle, produces hydrogen more efficiently than conventional methods and recycles heat, allowing for a more efficient power storage system.
  - – Reversible systems that can be used for both water electrolysis and fuel cells.
  - – Technology that directly separates hydrogen and carbon from fossil resources for purposes such as production of hydrogen.
- Discussions on energy resources that are currently not used in hydrogen production, such as fossil energy resources and sunlight, and explore a wide range of possibilities, including innovative potential resources for hydrogen production technology such as high-temperature geothermal energy, ocean energy, space solar power and high-temperature gas furnaces.

[Transportation and storage]

- Creation of highly efficient hydrogen liquefiers and long-lasting materials to hold liquid hydrogen
  - – Innovative technology such as hydrogen liquefiers that balance highly efficient liquefaction with large-scale liquefaction volumes through measures such as optimization of the freezing cycle to boost the cooling effect.
- Development of highly efficient low-cost energy carriers
  - – New synthesis technology such as organic hydride synthesis technology with lower energy consumption.
  - – Lightweight, high-capacity hydrogen storage materials.
  - – Technology to synthesize hydrogen carriers such as ammonia at lower temperatures and pressures.

[Use]

- Development of compact, highly efficient, highly reliable and low-cost fuel cell technology
  - – Solid oxide electrolysis cells that can operate at a high output even in lower temperatures.
  - – Highly efficient and durable polymer electrolyte fuel cells using zero or significantly lower quantities of rare metals.
- Development of innovative chemical synthesis methods using hydrogen and carbon dioxide
  - – Fuel and chemical synthesis technology that achieves a high activity level, high productivity and a long life even under reaction conditions of lower temperatures and pressures.

[11] Solid Oxide Electrolysis Cell. This technology uses high-temperature solid oxide (ceramic) electrolytes to electrolyze water into hydrogen and oxygen.

Supplement

When promoting the development of innovative technology, it is important to ensure that the technology can be publicly adopted as quickly as possible. To accomplish this, it is necessary to envision the ultimate use of the technology and work steadily within collaborative frameworks between industry, academia and the government based on promising ideas and industry needs concerning the production, transportation, storage and use of hydrogen in order to deliver the optimal overall system. Regular progress checks need to be carried out from the basic research stage.

2-3. (2) Promoting understanding among Japanese citizens and working with communities

While hydrogen is being used more and more widely in technology that is a part of Japanese people's lives, such as fuel-cell vehicles and buses, hydrogen stations and Ene-Farms, Japanese people do not yet have a sufficient understanding of the safety of hydrogen, the importance of using it and the potential this resource holds.

Hydrogen is a flammable gas that has a wide range of flammable temperatures and does not require much energy to ignite. Additionally, it is the lightest flammable gas on earth and disperses easily in air, so any leaks will disperse quickly and will soon fall below the concentration required for ignition. This means that hydrogen is unlikely to ignite or explode when it is managed appropriately, and can therefore be used safely.

In order to achieve the dramatic acceleration of hydrogen use that has been planned and make hydrogen energy a part of Japanese people's daily lives, it will be necessary to promote a deeper understanding of hydrogen throughout society at large by sharing information like this about the safety of hydrogen, along with information on why hydrogen energy is important and the potential it holds. The national government will therefore work with local government bodies and businesses and take every opportunity to inform people about this.

Each region uses energy differently, and initiatives concerning energy and the environment are being carried out by each local government and businesses in each region based on each region's specific characteristics. The national government will take this into account as it works to promote the use of hydrogen, supporting each region's hydrogen initiatives through popularization measures and regulatory reforms and strengthening collaborative frameworks with local government bodies across a wide area through regular sharing of information and exchanges of opinions.

Description in the Basic Hydrogen Strategy (excerpts)

- Citizens must gain an understanding of the safety of hydrogen and the significance of hydrogen use. To this end, the central government will adequately communicate information to citizens in cooperation with local governments and business operators.
- In a bid to promote hydrogen use, thegovernment will support hydrogen use initiatives in regional communities including those created by local governments and proactively utilize various regional councils and the "conference on local governments' cooperation in diffusing and promoting

FCVs" to share information with local governments, secure information sharing between local governments and implement policy measures efficiently.

Below is an action plan based on the direction indicated in the Basic Hydrogen Strategy. This contains specific measures to promote understanding among Japanese people and further strengthen cooperation with communities.

Action Plan

- Japan will make use of all opportunities to promote hydrogen use among Japanese people, such as the Tokyo Olympics and Paralympics in 2020 and EXPO 2025 Osaka, Kansai and will actively promote Japan's cutting-edge technology and our future vision for a "hydrogen society." Additionally, Japan will provide opportunities to learn about hydrogen and promote training of the personnel that will be needed in a "hydrogen society."
- Japan will strengthen collaborations with local government bodies across a wide area to enable horizontal expansion of cutting-edge measures and carry out strategies efficiently and effectively.

Supplement

Actively spreading information is the key to promoting understanding among Japanese people. As we shift from the technological development phase to the public implementation phase, it is particularly important to carry out information sharing activities with a strong understanding not only of manufacturers' and engineers' perspectives but the perspectives of consumers and citizens. A variety of media should be used, from websites and pamphlets to symposiums and events, to actively spread information on the safety and importance of hydrogen, the potential of hydrogen use and measures that are being carried out by the national government, in a form that is easy for citizens to understand. International events and forums that will be attended by many people from inside and outside Japan are also a prime opportunity for Japan to lead the way in promoting a "hydrogen society" for the future. The national government will make use of the Tokyo Olympics and Paralympics in 2020 to promote Japan's cutting-edge technology and the benefits and potential of hydrogen energy. Hydrogen produced from renewable energy sources in Fukushima Prefecture will be used in fuel cell vehicles and as an energy source for the Olympic and Paralympic Villages in 2020. The Tokyo Olympics and Paralympics are just one of many opportunities that will be taken; others include the International Hydrogen and Fuel Expo (FC Expo), G20 in 2019 and EXPO 2025 Osaka, Kansai. The maximum possible use will be made of Japan's world-leading hydrogen and fuel cell technology to promote Japan's advanced technology inside and outside Japan and to show the world a future vision for a "hydrogen society" where hydrogen is used in a variety of fields such as transportation, industry and power supply. This will be used as a springboard to further accelerate innovation in hydrogen and fuel cell technology and publicly implement that technology in the future.

Another important element in expanding and strengthening people's understanding about hydrogen is creating opportunities for people to learn about hydrogen from an early age, including about its safety and overall importance to Japan. If people have the opportunity to learn about hydrogen from a young age, it will generate more interest in research and technological development in the hydrogen and fuel cell fields, which will make it possible to develop the personnel who will be needed in the "hydrogen society" we want to build in the future.

To strengthen collaboration with local communities, the national government will actively make use of forums where the national government meets with regional government bodies, such as "the conference on local governments' cooperation in diffusing and promoting FCVs" and regional councils. Advanced measures and issues related to hydrogen will be shared and discussed on these occasions to promote the use of various support measures, roll advanced measures out and unify the execution of regulations concerning fuel cell vehicles and hydrogen stations.

2-4. Achieving a global "hydrogen society"

Initiatives to promote international collaborative programs concerning hydrogen are accelerating among governments and private sectors alike.

In December 2017, Japan was the first country in the world to announce a national government strategy concerning hydrogen, the Basic Hydrogen Strategy. With the EU and France announcing hydrogen strategies in 2018 and South Korea following suit in 2019, it is clear that nations and multinational regions are strategically promoting hydrogen use at a government level. Japan achieved another world first by holding the Hydrogen Energy Ministerial Meeting, the world's first global summit with hydrogen as the main topic, in October 2018. Ministry representatives from 21 nations, multiple regions and international organizations discussed the subject and released the Tokyo Statement, which defines initiatives to be taken by each country to promote the popularization and expansion of hydrogen energy. Other international collaborations between governments include the IEA and IPHE[12], where hydrogen energy is being actively discussed. In May 2018, Mission Innovation was launched as an international framework to promote greater government investment in research and development on clean energy, with Renewable and Clean Hydrogen set as Innovation Challenge 8. Sixteen countries and regions including Japan, the EU and Australia are participating in discussions to start multinational scientific research on hydrogen.

Initiatives are also underway in various industries. In January 2017, the Hydrogen Council was founded by 13 global corporations in fields such as energy and vehicles. Comprising top figures in the private sector around the world with over 54 companies involved as of January 2019, the Council will serve as a global task force for widespread provision and sharing of visions for the popularization of hydrogen technology. At the World Economic Forum in January 2019 (also known as the Davos Forum), a session on achieving a "hydrogen society" was held jointly by the Hydrogen Council, IEA and the organizers of the World Economic Forum. In addition to the Japanese Minister of the Economy, Trade and Industry, attendees included ministers from France, Germany, South Korea, New Zealand, Australia and South Africa, along with the Secretariat of the IEA and CEOs of companies belonging to the Hydrogen Council. Discussions were held to strengthen collaboration between government bodies and the private sector on a global scale.

Japan has taken the lead in proposing international standards on hydrogen such as ISO/TC197 (Hydrogen Technologies), IEC/TC105 (Fuel Cell Technologies) and UN/GTR13 (Global Technical Regulation on Hydrogen/Fuel Cell Vehicles). Ongoing initiatives are taking place in Japan to set international standards on points such as safety requirements and performance testing methods in these fields.

As a result of government support measures and industry initiatives like these, a total of around 10,000 FCVs and around 300 hydrogen stations are now being used around the world as of December 2018. New initiatives such as large-scale demonstration testing of power-to-gas technology and

[12] International Partnership for Hydrogen and Fuel Cells in the Economy

pipeline injection of hydrogen are spreading in various countries which will promote the use of hydrogen on a larger scale.

The Basic Hydrogen Strategy includes a statement about international collaboration that the national government will incorporate proposals from the private sector into its decisions on policies concerning international collaboration and make use of international frameworks such as IEA and PHE as it promotes collaboration.

Description in the Basic Hydrogen Strategy (excerpts)

- To expand hydrogen use, the government will cooperate with the Hydrogen Council and other organizations and adopt private sector policy proposals contributing to the expansion of the hydrogen market.
- Through the frameworks provided by government-level international organizations such as IEA and the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE), the government will actively provide foreign countries with Japanese initiatives as models for their policy development. The government will also promote cooperation between these organizations and promote their joint research in cooperation with foreign governments and private companies.
- The future international standardization of hydrogen technologies will continue to grow more important for Japan's development and commercialization of these technologies. As international trends in hydrogen gain increasing notoriety, Japan will increase its efforts to advance proposals at the ISO/TC19728 Committee on international standards involving hydrogen technologies in a bid to lead the world in the hydrogen field.
- Given that the United Nations has launched discussions on the revision of global technical regulations on hydrogen and fuel cell vehicles that Japan took the initiative in developing, Japan will promote technological development and cooperation with relevant organizations to continue leading the discussions.
- The government will revise domestic regulations on hydrogen stations and FCVs by adopting international standards in Japan that have been proven rational and safe, paving the way for devices that are produced under domestic specifications for hydrogen stations to be easily introduced into overseas markets.

Below are a road map and an action plan. These contain specific measures that incorporate the direction indicated in the Basic Hydrogen Strategy along with new initiatives such as the Tokyo Statement announced at the Hydrogen Energy Ministerial Meeting. These measures are aimed at achieving the goals of the Tokyo Statement so that Japan can continue to lead the world in hydrogen initiatives and make strong progress toward the building of a global "hydrogen society."

Road Map

- Japan will collaborate internationally to achieve the following initiatives outlined in the Tokyo Statement announced at the Hydrogen Energy Ministerial Meeting:
  - Japan will work on technological collaborations and promote standardization and harmonization of standards and regulations to reduce hydrogen supply costs and the prices of products such as fuel cell vehicles.
  - Japan will collaborate internationally on research and development to increase hydrogen use through measures such as ensuring safety in hydrogen stations and hydrogen storage facilities and building supply chains suited to the characteristics of each region.
  - Japan will promote surveys and evaluations of the potential for hydrogen use and the economic benefits and CO_2 reduction that will result to foster awareness about building a "hydrogen society."
  - Japan will promote education and advertising activities to gain greater public acceptance of hydrogen energy and use this for purposes such as expanding hydrogen businesses.

Action Plan

- Japan will make maximum use of international government frameworks to promote exchange of information on policies and joint investigations and research and show particular leadership in the fields where Japan is currently leading the world, such as mobility and supply chains, to promote deregulation and joint demonstration testing.
- Japan will publish the results of demonstration tests on the building of hydrogen supply chains in Japan and share the information with other countries to strengthen international collaborations so that an international supply chain can be built.
- Japan will discuss possibilities for a multifaceted framework and specific cooperation with other countries, in particular carrying out information exchanges, joint investigations and joint research with other leaders in this field, including the USA, Germany and France, and including comparisons of safety regulations and sharing information on matters such as accidents.
- Japan will actively share information on these initiatives with related countries so that this information can be used to create government policies in other countries.
- Japan will actively facilitate information exchanges between the government and the private sector and actively incorporate industries' needs and policy proposals into decision-making to strengthen collaboration between the government and the private sector on a global scale.
- Japan will actively make proposals related to international standards on hydrogen such as ISO/TC197 (Hydrogen Technologies), IEC/TC105 (Fuel Cell Technologies) and UN/GTR13 (Global Technical Regulation on Hydrogen/Fuel Cell Vehicles) to promote international standardization.

Supplement

In October 2018, ministry representatives from 21 nations, multinational regions and international organizations met in Tokyo for the Hydrogen Energy Ministerial Meeting, where they released the

Tokyo Statement, which defines initiatives to be taken by each country to promote the popularization and expansion of hydrogen energy. International discussion on how to accomplish the objectives of the statement is accelerating, with Japan leading the other countries and following up on progress toward the accomplishment of the Tokyo Statement.

The G20 Summit, a conference between ministers involved in energy and environmental conservation for sustainable growth will be held in Karuizawa in June 2019. With increasing global discussion about the prospect of a “hydrogen society,” discussion on hydrogen is expected at the summit. The second Hydrogen Energy Ministerial Meeting will be held in fall 2019, again in Japan. Progress on the Tokyo Statement since the first meeting in 2018 needs to be shared and initiatives will need to be strengthened further through international collaboration.

Chapter 3: Conclusion: Regular follow-ups to ensure the effectiveness of this Road Map

The success of Ene-Farm has been followed by the launch of fuel cell vehicles, marking a new step toward a "hydrogen society." With measures to change energy sources and reduce CO_2 underway around the world since the Paris Agreement was issued in November 2016, the world is increasingly looking to hydrogen as next generation energy. A variety of measures that promote the use of hydrogen energy are being undertaken in developed regions such as Europe and North America, as well as in developing nations that are experiencing an increasing demand for energy, such as China. This global spread shows the major potential for growth in the hydrogen market. Japan needs to accurately assess global trends like these and keep pace with them, while continuing to lead the world in the building of a "hydrogen society."

Japan therefore needs to think more concretely based on the shared goals and awareness that have been fostered between the parties that were involved in the establishment of the Roadmap, and make rapid, steady progress on road maps and action plans that are categorized into relevant individual fields. In particular, while the use of hydrogen has increased dramatically, the increase in the scale of the hydrogen market needs to be accompanied by measures to ensure safety and reduce costs. This will require collaboration between industry, academia and government along with active cooperation with relevant parties outside the applicable industries. To ensure solid progress, progress will need to be checked regularly, and there will occasionally be a need to evaluate projects and initiatives, identify issues to be solved, rebuild frameworks and discuss solutions or countermeasures, in order to respond to changes in social circumstances, amendments to regulations and shifting trends in areas such as technological development.

A working group comprised of experts such as researchers, specialists and journalists will be established in the Hydrogen and Fuel Cell Strategies Council for this purpose. Regular progress checks including the current status and the likelihood of achieving future targets will be carried out around once a year through means such as hearings with relevant companies in each field about matters such as their supply chain and hydrogen use. Verification of this nature will require accurate assessment of current progress in technology. Technological development and demonstration testing funded within the national budget will be quantitatively assessed to determine the progress of relevant parties and the current status of the technology in question. In the event that these progress checks indicate a need for a policy change, sufficient investigation and evaluation of the situation will be undertaken before carrying out a policy change or similar initiative.

This is how the Japanese government intends to proceed, taking a variety of approaches to bridge the gap between the perspectives of the organizations on the supply side and those on the demand side, and uniting the government and the private sector in active, all-encompassing strategies to lead the world in building a "hydrogen society."

Reference

Members and affiliates of the Hydrogen and Fuel Cell Strategies Council (as of March 12, 2019)

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Environmental Transport Policy Division, Environmental Management Bureau, Ministry of the Environment

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Meetings of the Hydrogen and Fuel Cell Strategies Council

Meeting 1: December 19, 2013

Topics: Hydrogen and Fuel Cells

Main Discussion Topics of the Hydrogen and Fuel Cell Strategies Council

Meeting 2: May 28, 2014

Topic: Discussion on Coordination

Meeting 3: June 19, 2014

Topic: Discussion on Coordination

*The Hydrogen and Fuel Cell Strategies Road Map was established and announced on June 23, 2014

Meeting 4: June 11, 2015

Topic: Progress of the Roadmap
Environmental Changes and New Discussion Topics since the Establishment of the Roadmap

Meeting 5: November 11, 2015
Topic: Policies, etc. for the Accomplishment of the Targets Indicated in the Roadmap

Meeting 6: February 17, 2016
Topics: Background and Key Points of the Revision of the Roadmap
Discussion on the Direction to be taken in the Revision of the Roadmap

Meeting 7: March 16, 2016
Topic: Discussion on Coordination of the Revision of the Roadmap

*The revision of the Hydrogen and Fuel Cell Strategies Road Map was performed and announced on March 22, 2016

Meeting 8: March 10, 2017
Topics: Progress of the Hydrogen and Fuel Cell Strategies Road Map
Initiatives to Revise Regulations Concerning Hydrogen Stations
Report of CO_2-free Working Group

Meeting 9: June 1, 2017
Topics: The 1st Ministerial Meeting on Matters Such As Renewable Energy and Hydrogen
New Frameworks for the Popularization of Hydrogen Stations
Results of Investigation and Analysis on Strategic Placement of Hydrogen Stations
Progress in Revisions of Regulations Related to Hydrogen Stations
Potential Configurations of Hydrogen Energy Generation and Supply Chains
Deliberation of Methods for Evaluating CO_2 Emissions in Hydrogen Production According to IPCC

Meeting 10: September 22, 2017
Topic: Basic Hydrogen Strategy

Meeting 11: November 6, 2017
Topic: Tentative Plan for the Basic Hydrogen Strategy

Meeting 12: December 7, 2017
Topic: Basic Hydrogen Strategy (Draft)

Meeting 13: July 5, 2018

Topics: The 5th Basic Energy Plan and the Basic Hydrogen Strategy
Directions to be taken in the Strengthening of International Collaborations
Plan for Establishment of JHyM and Maintenance of Hydrogen Stations
Status of Initiatives for Revision of Regulations
Progress of Hydrogen and Fuel Cell Strategies Road Map
Main Revisions to Hydrogen and Fuel Cell Strategies Road Map

Meeting 14: December 21, 2018

Topic: Directions to be taken in the Revision of the Hydrogen and Fuel Cell Strategies Road Map – Establishment of a New Action Plan

Meeting 15: February 25, 2019

Topic: Hydrogen and Fuel Cell Strategies Road Map (Draft)

Meeting 16: March 12, 2019

Topics: Revision of the Hydrogen and Fuel Cell Strategies Road Map
Follow-up of the Hydrogen and Fuel Cell Strategies Road Map