TOKYO
METROPOLITAN
GOVERNMENT

Tokyo H_2
Hydrogen Vision

Introduction

We are witnessing that the stable supply of energy can be easily threatened by international conflicts, earthquakes, etc.

The climate crisis, with effects such as unprecedented heavy rains or typhoons, is already impacting our daily lives.

The Tokyo Metropolitan Government (TMG) is mobilizing all of its policies to realize “Carbon Half” by 2030, halving greenhouse gas emissions compared to 2000, and a decarbonized society by 2050 beyond that. It is becoming more urgent to ensure the sustainability of the lives and economic activities of Tokyo residents, including the stable supply of energy, as well as the environmental sustainability.

The expanded use of renewable energy and hydrogen that supports it are decisive measures in terms of both climate action and the stable supply of energy.

Hydrogen, which can be stored in large quantities and for a long term, is expected to contribute to decarbonization in all fields as an adjusting mechanism for renewable power to support its massive introduction and supply.

Hydrogen will also help diversify energy sources and contribute to energy security as it can be produced from a variety of resources.

This Tokyo Hydrogen Vision illustrates how hydrogen will be used in the future and our visions for 2050. It also describes the direction of our efforts for the development of hydrogen initiatives toward the milestone of 2030.

We hope that this vision will help readers imagine a future in which hydrogen energy has become widespread, Tokyo residents feel closer to hydrogen, and businesses consider participating in the hydrogen business.

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Chapter 1

CLIMATE CRISIS AND HYDROGEN ENERGY

Why is hydrogen needed as the world is facing the climate crisis?

This chapter describes the characteristics of hydrogen and its significance in decarbonization.

Chapter 1 1. Climate Crisis and the Realization of a Decarbonized Society

The climate crisis becoming even further aggravated

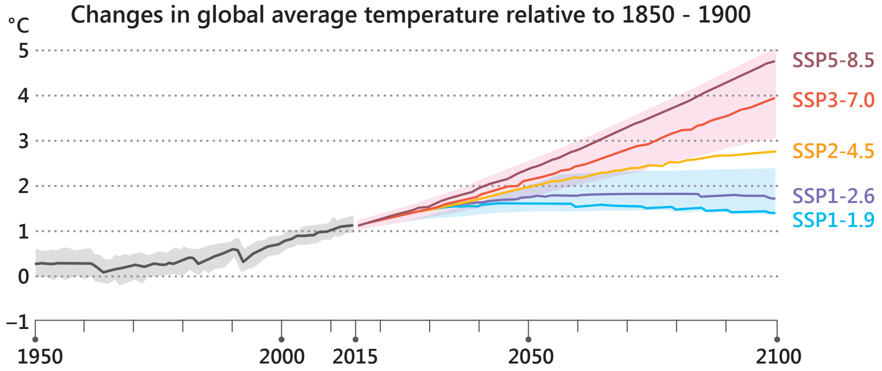
The impacts of the climate crisis have extended to our daily lives as record natural disasters, such as heat waves, wildfires, floods, typhoons, and heavy rains, occur almost every year around the world and in Japan with the number of such disasters caused by climate change increasing five-fold in the last 50 years according to the WMO*1 report in August 2021.

The global average temperature is rising, and the trend of warming has been accelerating in recent years.

The IPCC*2 concludes in its report*3 published in August 2021 that "It is unequivocal that human influence has warmed the atmosphere, ocean and land."

*1 World Meteorological Organization (UN specialized institution)
*2 Intergovernmental Panel on Climate Change
*3 Working Group I Contribution to the Sixth Assessment Report (the Physical Science Basis)

Forest fires in USA (2021)
Source: US NIFC website



Source: IPCC AR6/WG1 Report, Summary for Policymakers

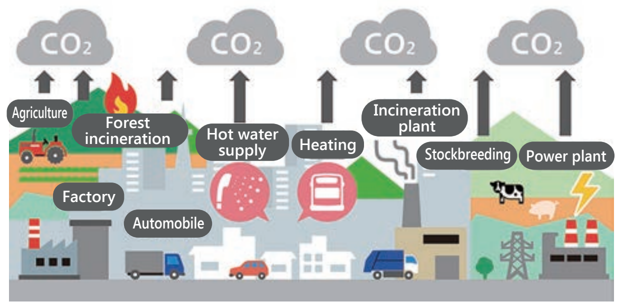
Heavy rains in Saga Prefecture etc. (August 2021)
Source: Website of the Geospatial Information Authority of Japan

The cause: CO_2 and other GHG emissions

The cause of global warming that causes climate change is a continuous increase in CO_2 and other GHGs.

CO_2 is mainly generated by burning fossil fuels, including coal, petroleum, and natural gas.

We emit CO_2 in every aspect of our economic activities and lives.



* As for GHGs emitted from Tokyo, CO_2 accounts for approximately 90% and other GHGs, such as fluorocarbons, account for approximately 10% in CO_2 equivalent.

Aiming for a decarbonized society with net zero CO_2 emissions by 2050

TMG is aiming for a decarbonized society with net zero CO_2 emissions by 2050. What should we do to realize a decarbonized society?

First of all, it is important to reduce energy consumption and increase the utilization of renewable energy, such as solar power generation. However, an adjusting mechanism is needed for the stable utilization of renewable energy that does not generate a constant amount of power depending on the season or weather.

In addition, electricity is not the only energy we use. How can we decarbonize different types of energy, including heat and transportation fuels?

Hydrogen mascot "Suison"
© Tokyo Environmental Public Service Corporation

Hydrogen is attracting attention under these circumstances.

2. Why Is Hydrogen Needed?—from the perspective of climate crisis and energy security

Hydrogen will power the future

Hydrogen is the lightest and most abundant atom on the earth and can be used as energy through combustion or chemical reaction.

Fuel cell vehicles and buses powered by hydrogen have already started running in Tokyo, and hydrogen energy is spreading in society.

Hydrogen can be made from a variety of resources

Hydrogen does not emit CO_2 when used.

There are many ways to make hydrogen. Currently, it is often made from natural gas, by-products of industrial processes, etc. But, full-scale use of **hydrogen derived from renewable energy, so-called Green Hydrogen**, which does not emit CO_2 even during production, is expected in the future.

TMG considers **Green Hydrogen as a pillar for realizing a decarbonized society**.

Hydrogen will contribute to energy security

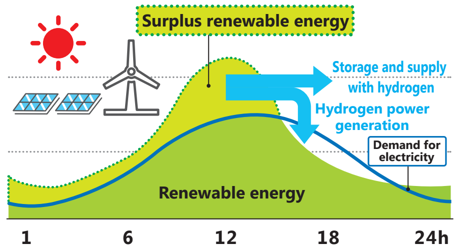
Japan relies on imports from overseas for most of its energy, making it vulnerable to international affairs. In order to protect our social life and economic activities, it is necessary to diversify energy sources.

Utilizing hydrogen produced from different resources, including renewable energy at home and abroad, will lead to energy security and the stable supply of energy.

Green Hydrogen will support the massive introduction and supply of renewable energy

The decarbonized society TMG is aiming for by 2050 assumes that renewable energy will have been introduced and supplied in large quantities as a major energy source.

However, the amount of power generated by sunlight, wind, and other renewable energy fluctuates depending on the season and weather. To maintain a balance between supply and demand in some regions of Japan, the output of solar and wind power generation is restricted when the amount of power generated, which includes renewable energy, exceeds the demand for electricity.



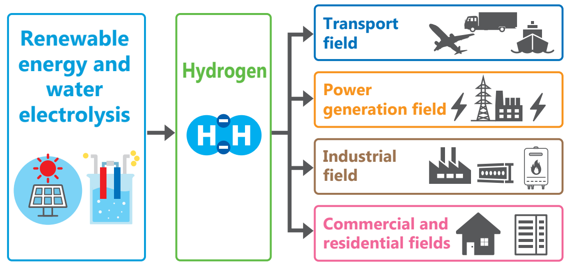
One of the features of hydrogen is that it would allow a large amount of energy to be stored for extended periods. For example, electricity generated by solar power generation in spring when electricity demand is low can be stored as hydrogen which then can be used as electricity again in summer or winter when electricity demand is high.

In this way, Green Hydrogen is anticipated to act as an adjusting mechanism for renewable energy that will be introduced and supplied in large quantities.

Green Hydrogen will contribute to the decarbonization of energy in various fields

Hydrogen can contribute to the decarbonization of energy in various fields.

Taking the transport field as an example, it is expected that hydrogen will be used as transportation fuel not only for fuel cell vehicles and buses that have already been commercialized, but also for large ships, aircraft, etc. in the future.



As for electricity, while fuel cells that generate electricity from hydrogen, such as ENE-FARM, have been commercialized, it is expected that hydrogen power generation, which burns hydrogen directly at large power plants, will be realized in the future.

Hydrogen is also a promising candidate for the decarbonization of thermal energy. It is expected to meet the heat demand of the commercial and residential fields and be used as a high-temperature heat source in the industrial field where electrification is difficult.

If such hydrogen is converted into Green Hydrogen, it will contribute to further decarbonization.

Other advantages of hydrogen:

● Use in the event of a disaster

Fuel cell vehicles and buses have a large power supply capacity. In the event of a power outage or other emergency, they can be used as an emergency power source through a portable vehicle-to-load system to supply electricity.

● Economic spillover

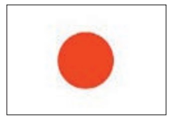
Japan is technologically ahead in multiple areas of hydrogen-related technology. It is expected to become an internationally competitive industry in the future as some private surveys predict that the hydrogen-related market in Japan will exceed JPY 4 trillion by FY 2035.

COLUMN

Hydrogen: Energy Attracting the World's Attention

Japan and other major countries around the world are accelerating a variety of efforts, including the formulation of national strategies for the introduction of hydrogen, which is the key to achieving carbon neutrality.

Each country's trends in hydrogen



Japan

- Formulated the world's first Basic Hydrogen Strategy in 2017
- Considered hydrogen as one of the priority areas in the 2020 Green Growth Strategy
- Formulated the 6th Strategic Energy Plan in 2021 to position hydrogen as a new resource and accelerate its social implementation, looking ahead to the carbon-neutral era

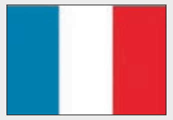
EU

- Announced the Hydrogen Strategy for a Climate-Neutral Europe in 2020
  Aiming to introduce a 40-GW water electrolyzer and 10-million-tonne Green Hydrogen by 2030. Low carbon hydrogen (hydrogen from fossil fuels with CCUS* etc.) will also be used in the short to medium term
- Launched the public-private partnership Clean Hydrogen Alliance to accelerate investment

* Carbon dioxide Capture, Utilization and Storage

Germany

- Formulated the National Hydrogen Strategy in 2020
  Aiming to expand the scale of the water electrolyzer to 5 GW by 2030 to supply 14-TWh Green Hydrogen.
  Electricity required for water electrolysis is exempted from renewable energy charges
  Cooperating with Africa and other regions suitable for Green Hydrogen production for large-scale hydrogen imports in the future

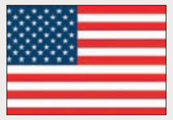


France

- Announced the National Hydrogen Strategy in 2020
  Consisting of three pillars: creation of a hydrogen production sector and decarbonization of the manufacturing industry through water electrolysis; development of large-scale hydrogen fuel mobility, including airplanes; and research, innovation, and human resource development
  Aiming to install water electrolyzers of 6.5 GW in total by 2030

UK

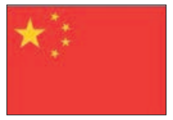
- Announced a hydrogen strategy in 2021 based on the Ten Point Plan for a Green Industrial Revolution
  Showing a plan to mass-produce Green and Blue Hydrogen
  Presenting a roadmap to develop hydrogen production capacity of 5 GW by 2030 and make hydrogen available in a wide range of fields, including steel, power systems, and large ships



USA

- Formulated the Hydrogen Program Plan (Department of Energy) in 2020 to clarify the direction of five items: hydrogen production, transportation, storage, conversion, and applied technology
- FCVs*1 are introduced according to the ZEV*2 regulations started in California which will also apply the ZEV regulations to commercial vehicles from 2024

*1 Fuel Cell Vehicles
*2 Zero Emission Vehicle that does not emit CO_2 or other exhaust gases during driving



China

- Updated the FCV deployment targets* in 2020, including increasing FCVs to 1 million by 2035 and model change to hydrogen-powered commercial vehicles
  The focus is now on selecting multiple model cities in China in 2020 as well as supporting the development of core technologies and construction of infrastructure for the FCV industry with purchase subsidies no longer applied to FCVs
  Accelerating the construction of a hydrogen supply chain including fuel cells centered on China itself

* Energy Saving and New Energy Vehicle Technology Roadmap

Korea

- Implemented the Hydrogen Economy Promotion and Hydrogen Safety Management Act (Hydrogen Act) in 2021
  Developing a system, support measures, infrastructure construction, and safety regulations for transition to hydrogen economy
- Formulated the Hydrogen Energy Leadership National Vision in 2021 to announce that the amount of Green Hydrogen and Blue Hydrogen will be 250,000 tonnes and 750,000 tonnes respectively, and the amount of hydrogen used will be 3.9 million tonnes by 2030

Visions for 2050 and Actions toward 2030

▶ Positioning of Chapters 2 and 3

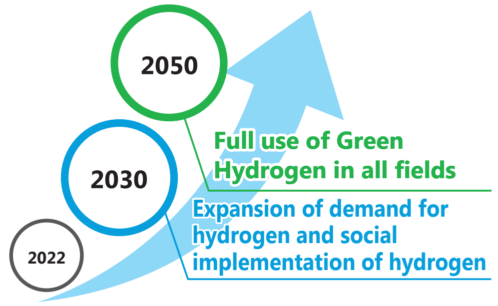
How will hydrogen, which has a variety of advantages and future potential, spread in society?

Chapter 2 describes TMG's visions and medium- to long-term outlook for how hydrogen will be used in 2050.

Chapter 3 describes the direction of TMG's efforts for the development of hydrogen initiatives toward the milestone of 2030.

Chapter 2	Visions for 2050
Chapter 3	Direction of actions toward 2030

▶ Full use of Green Hydrogen in all fields by 2050, expansion of demand for hydrogen and social implementation of hydrogen toward 2030



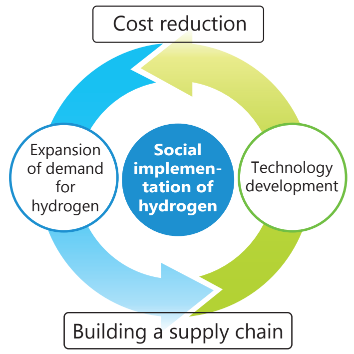
In the decarbonized society of 2050, Green Hydrogen is expected to be fully utilized in all fields and contribute to decarbonization in transport and other fields.

To that end, it is necessary to start building the foundation for the full use of Green Hydrogen earlier toward 2030.

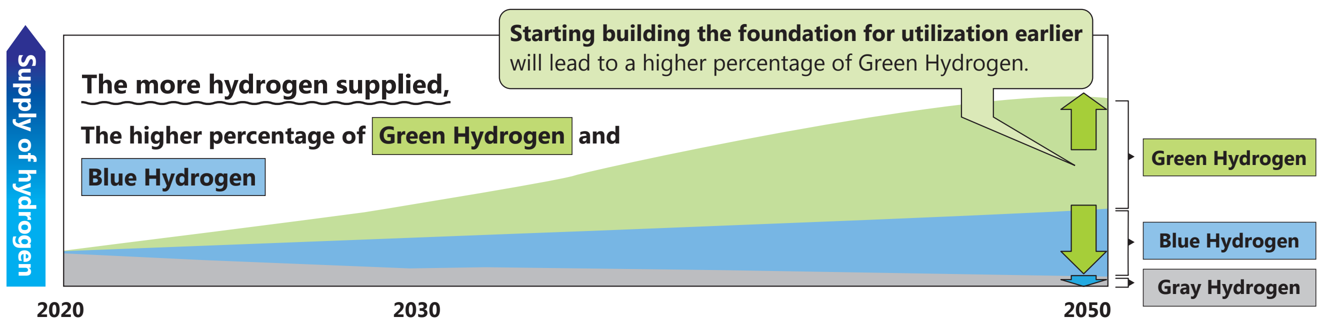
On the other hand, Green Hydrogen will not become widespread in a single step. For the spread of hydrogen energy, there remain several challenges, such as the need to reduce production costs and build a supply chain. To solve these challenges, it is essential to expand the demand for hydrogen in all fields and promote technology development and mass production.

Therefore, during the transition period toward the full-scale spread of Green Hydrogen, it is necessary to promote the social implementation of hydrogen energy earlier without eliminating Blue Hydrogen and Gray Hydrogen.

Chapter 3 will detail the efforts for the expansion of the demand for hydrogen and the social implementation of hydrogen.



■ Image of expansion of Green Hydrogen



Source: Global Hydrogen Review 2021, IEA

Does hydrogen have a color?	Hydrogen has the advantage that it can be produced from a variety of resources on Earth. Hydrogen itself is colorless and transparent, but it may be expressed in different colors, green, blue, or gray, for example, due to differences in the production process.
Green Hydrogen (from renewable energy)	Produced by electrolyzing water using electricity derived from renewable energy
Blue Hydrogen	Made from fossil fuel but does not release CO_2 into the air as CO_2 generated during the production process is captured and stored (CCS*)
Gray Hydrogen	Made from fossil fuels, such as natural gas and petroleum

▶ City and energy

A lot of energy is consumed in large cities as many people live within them and they are a hive of economic activities.

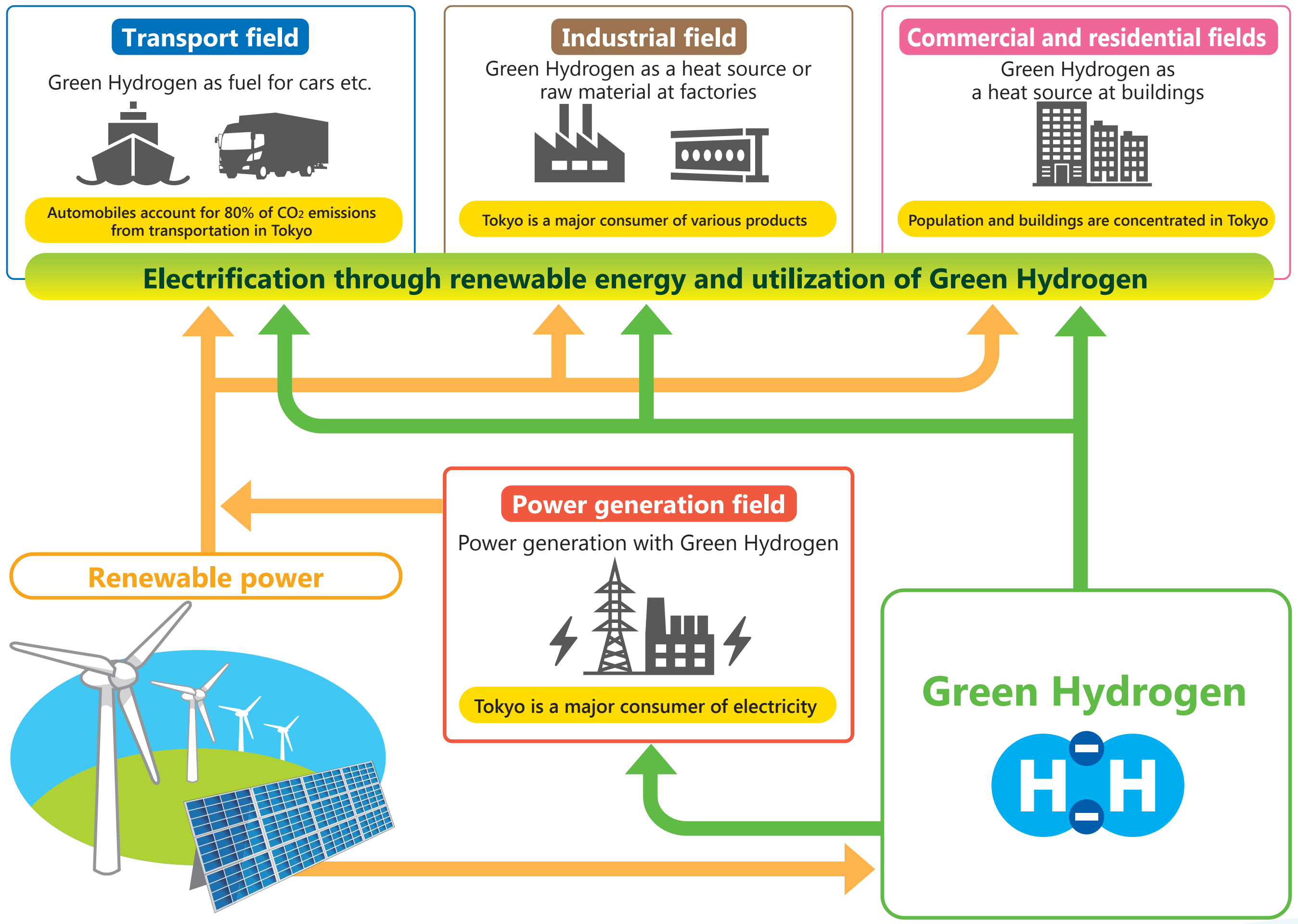
Tokyo is one such large city and is faced with the enormous challenge of decarbonizing the energy used by the many buildings and automobiles within its confines. In addition, since it is also a major consumer of resources and products, the energy consumed at and CO_2 emitted from factories and power plants located outside Tokyo should also be considered in this context.

As a large city, Tokyo has a responsibility to contribute to CO_2 emissions reductions inside and outside Tokyo, and must accelerate its actions in all fields.

To that end, it is necessary to review a lifestyle based on mass consumption of resources and products, make renewable energy a major energy source, and promote the expanded use of hydrogen energy that supports it.

The following chapters describe TMG's visions for how hydrogen will support the spread of renewable energy and how it will be utilized in the transport, power generation, industrial, commercial, and residential fields. These chapters also show the direction of TMG's efforts for the spread of renewable energy.

For the new use of hydrogen in the future, technology development is currently underway around the world with innovations expected to be introduced. It is possible that ways to utilize hydrogen will expand beyond what is currently recognized, posing the need to keep an eye on their trends and support their development.



Chapter 2

VISIONS FOR 2050

How Will Hydrogen Be Used?

How will hydrogen be used in the 2050 decarbonized society?

How will hydrogen become widespread in society toward 2050?

This chapter summarizes the medium- to long-term outlook based on the current trends in technology development and the visions TMG is aiming for.

Chapter 2 1. By 2050, Green Hydrogen made from renewable energy will play an active role

By 2050, it is expected that all hydrogen used will be CO_2-free, and most of it will be Green Hydrogen made from renewable energy.

Initial stage — Cases of introducing Green Hydrogen will be accumulated [by around 2025]

Efforts for the full use of Green Hydrogen have started moving rapidly as large-scale projects to produce hydrogen with renewable energy are considered all over the world, and an experimental study is underway at one of the world's largest hydrogen production plants using solar power generation in Fukushima Prefecture of Japan.

It is expected that these projects will help accumulate knowhow and lead to a reduction in costs toward the full use of Green Hydrogen.

Medium term — The foundation for the use of Green Hydrogen will be established [by around 2030]

Green Hydrogen is expected to rapidly become widespread in the world as Europe aims to produce 10 million tonnes of hydrogen from renewable energy sources by 2030.

In Japan, it is expected that the foundation for the use of Green Hydrogen will be established in parallel with the start of the commercialization of an international hydrogen supply chain as the national government aims to supply more than approximately 420,000 tonnes of clean hydrogen (produced with fossil fuels with CCUS or renewable energy) by 2030.

Long term — Green Hydrogen will be fully utilized in all fields. Green Hydrogen will support the massive introduction and supply of renewable energy [by around 2050]

By 2050, Green Hydrogen will be fully utilized in all fields and support the decarbonized society.

As described in Chapter 1, hydrogen allows energy storage in large quantities and for a long term. By 2050, Green Hydrogen is expected to act as an adjusting mechanism, supporting the massive introduction and supply of renewable energy and the stable supply of energy.

In addition, as described in Sections 2 and 3 of Chapter 2, Green Hydrogen is also expected to contribute to the decarbonization of energy in various fields.

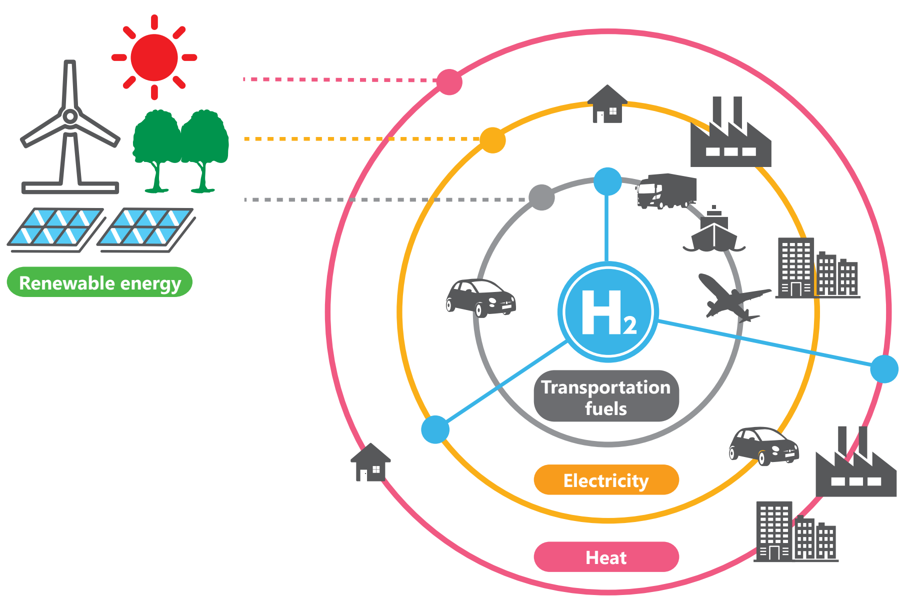
● Green Hydrogen will link energy sources and contribute to local production and consumption and stable supply

By 2050, Green Hydrogen will play a role in connecting different types of energy.

If renewable power is used to produce hydrogen, it can be stored for a long period of time and converted into energy required at any specific time, such as electricity, heat, or transportation fuel, enabling the effective use and stable supply throughout the energy spectrum.

In addition, it is expected that these characteristics of hydrogen will be utilized to promote local production and consumption of energy that enhances local resilience.

In the islands and other areas that have an independent power grid and are susceptible to output fluctuations of renewable energy, hydrogen is expected to serve as a balance for these energy sources together with a storage battery.



● Green Hydrogen will be procured in large quantities and at low cost at home and from abroad, and pipelines will also be utilized

By 2050, the cost of producing renewable power will have decreased, and Green Hydrogen is expected to be supplied at a lower cost.

In addition to Green Hydrogen produced with renewable energy in Japan, it is also assumed that Green Hydrogen produced with a large amount of renewable energy overseas will be imported, which is expected to contribute to the stable supply of energy. Currently, technology development and verification for transporting a large amount of hydrogen by sea is underway.

A pipeline will be added to transportation methods in Japan, expected to be laid in part of Tokyo.

Verification project for building an international hydrogen supply chain

In order for hydrogen energy to become widespread, hydrogen must be cost-competitive with other energy.

In Japan, efforts are being made to achieve the hydrogen supply cost of JPY 30/Nm^3 (free on board price) by 2030 and further reduce the cost to JPY 20/Nm^3 or less by 2050. * 1 Nm^3 ≈ 0.09 kg (0°C, 1 atm)

● Verification for building a liquid hydrogen supply chain

When cooled to minus 253°C, hydrogen changes from a gas to a liquid with its volume reduced to approximately 1/800. To transport the liquid hydrogen safely and in large quantities, Japanese heavy industry manufacturers built the world's first liquid hydrogen carrier and verified long-distance marine transportation.

They have started efforts aiming at increasing the size of liquid hydrogen carriers and land-based liquid hydrogen tanks and developing technology to further improve liquefaction efficiency with the goal of building a new integrated international commercial supply chain that covers production, liquefaction, shipping, marine transportation, and acceptance of hydrogen.

Image of liquid hydrogen carrier under development

© Kawasaki Heavy Industries, Ltd.

● Verification for building an MCH (methylcyclohexane) supply chain

The organic chemical hydride method* using MCH decreases the volume of hydrogen gas to about 1/500 and allows it to be transported as a liquid at a normal temperature and pressure using the existing petroleum infrastructure.

In 2020, four private businesses completed the verification of an international hydrogen supply chain between Brunei and Japan.

They have started the establishment of dehydrogenation technology (technology for extracting hydrogen) that uses oil refining equipment of refineries and commercialization verification for building the MCH supply chain.

Specifically in the verification, MCH produced from hydrogen in Brunei will be delivered to Japan, and hydrogen will be extracted (dehydrogenated) from MCH for use.

Verification of the international transportation of MCH

© Advanced Hydrogen Energy chain Association for technology Development (AHEAD)

* A technology that lets hydrogen react with toluene etc. to form a compound, such as methylcyclohexane (MCH), which is stored and transported at a normal temperature and pressure, and dehydrogenated at its final destination for utilization.

Metal that stores hydrogen: Solid metal hydride

In addition to liquid hydrogen and MCH, another method to store a large amount of hydrogen is solid metal hydride which uses the property of metals to absorb hydrogen. Solid metal hydride is heavy as it is a metal, has a high energy density, and can store hydrogen at an almost normal temperature and pressure.

Alloys consisting of abundant and inexpensive metals are being developed to reduce costs.

Solid metal hydride

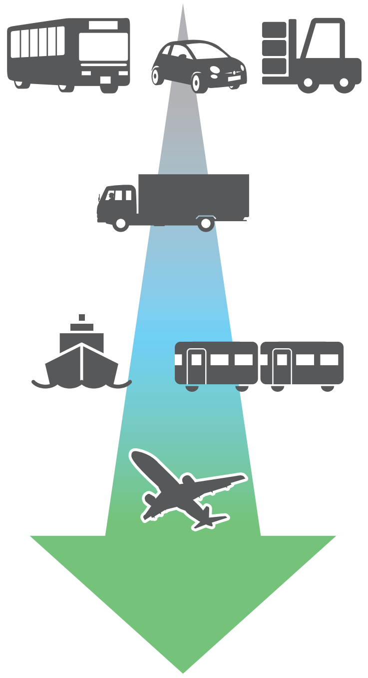
© Japan Metals & Chemicals Co., Ltd.

2. By 2050, hydrogen will contribute to decarbonization in the transport field

By 2050, Green Hydrogen is expected to be used as transportation fuel for automobiles, ships, aircraft, etc. contributing to decarbonization.

Initial stage — Utilization of hydrogen for passenger cars, buses, and trucks [by around 2025]

Hydrogen-powered automobiles, buses, and forklifts have already been introduced to the market. Hydrogen has an advantage for large vehicles and long-distance cruising, and it is expected to be a useful solution for trucks and other large commercial and service vehicles in the near future.



Medium term — Utilization of hydrogen for ships [by around 2030]

It is expected that fuel cell ships will be introduced for short-distance and small-size applications, and hydrogen fuel ships that directly burn hydrogen will be introduced for long-distance and large-size applications.

The national government aims for the commercial operation of zero-emission ships that use alternative fuels, such as hydrogen and ammonia*, ahead of the conventional target year, 2028.

* Ammonia is composed of hydrogen and nitrogen, and is expected to be used as a medium for carrying hydrogen (hydrogen carrier) and as a fuel.

Long term — Utilization of hydrogen for aircraft and other large transportation equipment [by around 2050]

By around 2050, it is anticipated that hydrogen will be used for hydrogen aircraft and other larger transportation equipment. Overseas aircraft manufacturers have already announced that they are aiming to bring hydrogen aircraft to the market by 2035, and Japanese businesses have also started research and development on hydrogen aircraft.

In addition, hydrogen is expected to be used for a variety of transportation equipment, including the railroad.

Development by Japanese businesses: Utilization of hydrogen for ships and aircraft

● Utilization for ships

Japanese businesses are developing fuel cell ships and hydrogen fuel ships in anticipation of their use.

- **Fuel cell ships**
  In Japan, Safety Guidelines for Hydrogen Fuel Cell Ships have been formulated to further promote the development and practical application of fuel cell ships, and Japanese businesses are conducting verification tests accordingly.

Image of fuel cell ship

© Toshiba Energy Systems & Solutions Corporation

- **Hydrogen fuel ships**
  To realize hydrogen fuel ships, it is essential to develop hydrogen fuel engines and tanks, and fuel supply systems. Japanese businesses have started developing the engines which need advanced combustion control technology and fuel injection technology due to the high combustion speed of hydrogen and other reasons.

● Hydrogen aircraft

For the realization of hydrogen aircraft, Japanese heavy industry manufacturers have begun efforts to develop core technologies, including hydrogen combustors, liquid hydrogen tanks, and hydrogen supply systems. When the required amount of liquid hydrogen is loaded, it needs approximately four times the volume of existing jet fuel. Research and development is being carried out to address such technical issues.

It is expected that hydrogen aircraft will be put into practical use in sequence with propulsion methods selected according to their size and flight distance. For example, it is envisioned that small aircraft equipped with fuel cells will be developed for introduction in the 2030s or later.

Image of hydrogen aircraft

© Kawasaki Heavy Industries, Ltd.

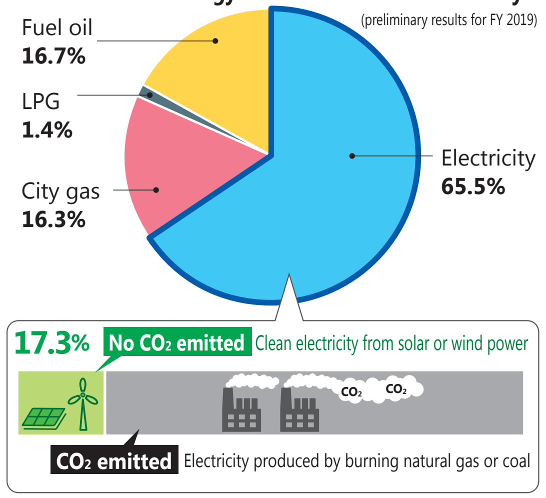
3. By 2050, hydrogen will contribute to decarbonization in a variety of fields

(1) Power generation field

Hydrogen will contribute to decarbonization in a variety of fields in addition to the transport field.

By 2050, it is expected that Green Hydrogen will be utilized for hydrogen power generation which burns hydrogen instead of fossil fuels to generate electricity.

■ Breakdown of energy-related CO_2 emissions in Tokyo (preliminary results for FY 2019)



Initial stage — Utilization of hydrogen for regional power generation [by around 2025]

In Japan, small-scale (1-MW class) hydrogen power generation (unmixed combustion) has already been verified on production equipment.

Hydrogen is expected to be utilized also for small-scale regional power generation, including the utilization of commercial and industrial fuel cells of several-hundred-kW or higher classes that have already been commercialized.

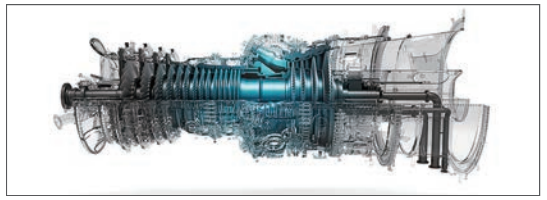
Medium term — Commercialization of hydrogen power generation (mixed combustion) accounting for 1% of power generation mix [by around 2030]

Hydrogen power generation (mixed combustion) is expected to be commercialized in parallel with the progress of technology development and verification of production equipment.

The government forecasts that hydrogen and ammonia will cover about 1% of the power generation mix in FY 2030.

In order to realize the commercialization of hydrogen power generation, it is important that a large-scale supply chain of inexpensive hydrogen is built in an integrated manner in addition to dealing with technical aspects.

Hydrogen gas turbine



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Long term — Green Hydrogen acting as an adjusting mechanism to support the decarbonization of electricity [by around 2050]

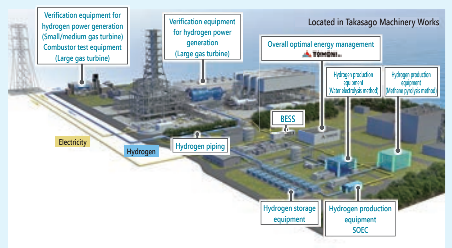
If hydrogen power generation (unmixed combustion) based on Green Hydrogen is realized by around 2050, it will contribute to the decarbonization of electricity and help stabilize the power grid as an adjusting mechanism, contributing to the massive introduction and supply of renewable energy.

Development by Japanese businesses: Hydrogen power generation

Currently, more than 70% of the electricity generated in Japan is produced by burning fossil fuels, such as natural gas and coal, at thermal power plants.

Japanese businesses are developing technologies to realize hydrogen power generation.

Verification equipment for hydrogen production/storage/power generation



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● Success in 30% hydrogen mixed combustion

A Japanese heavy industry manufacturer has succeeded in a mixed combustion test using 30% (volume ratio) hydrogen under conditions equivalent to an output of 700 MW. In order to verify power generation through mixed combustion using 30% hydrogen on a large gas turbine for production toward early commercialization, it has started efforts for installing equipment that enables consistent verification of technologies ranging from hydrogen production to power generation.

● Success in unmixed hydrogen combustion on small equipment

A Japanese heavy industry manufacturer has been conducting a verification project of 1-MW class gas turbine power generation through mixed combustion of hydrogen and natural gas and unmixed combustion of hydrogen. In 2018, in Kobe City of Hyogo Prefecture, it succeeded in supplying thermoelectric power to urban districts through power generation with a 100% hydrogen-fueled gas turbine for the first time in the world.

Japan is technologically ahead in the field of hydrogen power generation with Japanese businesses participating in large-scale hydrogen power generation projects overseas.

Verification of cogeneration with a hydrogen gas turbine

© Kawasaki Heavy Industries, Ltd.

Chapter 2

3. By 2050, hydrogen will contribute to decarbonization in a variety of fields

(2) Industrial field (heat demand/raw materials)

By 2050, Green Hydrogen is expected to be utilized for heat demand and raw materials in the industrial field where electrification is difficult, and contribute to its decarbonization.

Long term Utilization of hydrogen for heat demand and raw materials in the industrial field [by around 2050]

By around 2050, Green Hydrogen is expected to be utilized as a heat source required for industrial processes.

Many of the high-temperature heat demands in the industrial field are economically, calorically, and structurally difficult to electrify, causing consideration that hydrogen be used as fuel.

To decarbonize the steel field, using hydrogen as a reducing agent in the steel making process is being considered, and research is underway in Japan.

Technological innovation as well as large-scale and inexpensive hydrogen supply is important to decarbonize the steel field.

The utilization of synthetic methane, synthetic fuel, etc., which are described on the next page, is foreseen as a good candidate for the industrial field. It is expected that decarbonization will progress in stages as existing equipment and infrastructure become available.

Decarbonization of thermal energy

Speaking of energy, we tend to focus on electricity, but thermal energy is widely used in industrial applications, such as boilers and combustion furnaces, as well as for hot water supply at and heating of buildings, and is mainly fueled by city gas and petroleum products.

It is important to "electrify" thermal energy by renewable energy as much as possible and then decarbonize the remaining thermal energy.

There are multiple options to decarbonize heat: direct use by laying hydrogen piping, utilization of synthetic fuels, such as synthetic methane using hydrogen, and mixing of hydrogen in gas pipes. It is necessary to discuss which one to choose according to technological development trends in the future.

For the decarbonization of heat, it is also necessary to discuss from the perspective of resilience through a multi-layered energy infrastructure of power grids and gas pipes.

COURSE 50 Project

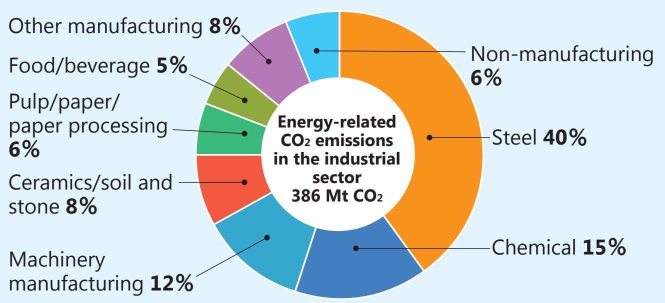
● Utilization of hydrogen in the steel industry

The steel industry is a core industry that forms the basis of other industries, with its energy-related CO_2 emissions accounting for about 40% of the entire industrial sector. A large amount of CO_2 is emitted in the steel making process, particularly when using a blast furnace.

In that process, there is a stage called reduction, which removes oxygen from iron ore, using a lump of carbon called coke as the reducing agent. As an effort to reduce CO_2 emissions, businesses and universities work together to promote the "CO_2 Ultimate Reduction in Steelmaking Process by Innovative Technology for Cool Earth 50 (COURSE50)" research that utilizes hydrogen as part of the reducing agent.

They have so far developed element technologies, such as iron ore reduction and CO_2 separation and recovery using hydrogen. As a comprehensive technology development based on the combination of these technologies, they are carrying out demonstration experiments using a test blast furnace completed in 2016, aiming to put the first unit into practical use by around 2030.

CO_2 emissions in the industrial sector in FY 2019



Source: Greenhouse Gas Emission Data of Japan in 2019, National Institute for Environmental Studies

Test blast furnace for demonstration experiments

© NEDO/Japan Iron and Steel Federation: COURSE 50

(3) Commercial and residential fields (heat demand)

By 2050, Green Hydrogen is expected to be utilized for methanation*, the direct use of hydrogen, etc. contributing to the decarbonization of heat demand in the commercial and residential fields.

* Technology for synthesizing methane, the main component of city gas, from hydrogen and CO_2

Initial stage Utilization of fuel cells [by around 2025]

In Tokyo where many buildings are concentrated, thermal energy is used for the hot water supply at buildings and heating of them.

At present, it is important to promote the development of methanation and other heat decarbonization technologies while promoting CO_2 emissions reductions by utilizing fuel cells.

Medium term Introduction of methanation [by around 2030]

Methanation is expected to be introduced by around 2030. The national government aims to increase methane synthesized by methanation up to 1% in the existing infrastructure by 2030.

In addition, it is expected that decarbonization will progress in stages thanks to technological progress, such as the cost reduction of Green Hydrogen production, the construction of a supply chain, and the direct use of hydrogen through pure hydrogen fuel cells.

Long term Decarbonization of heat [by around 2050]

It is anticipated that heating in the commercial and residential fields will have become decarbonized by around 2050, as city gas etc. become decarbonized as a result of the spread of methanation and the direct use of Green Hydrogen through fuel cells and combustion.

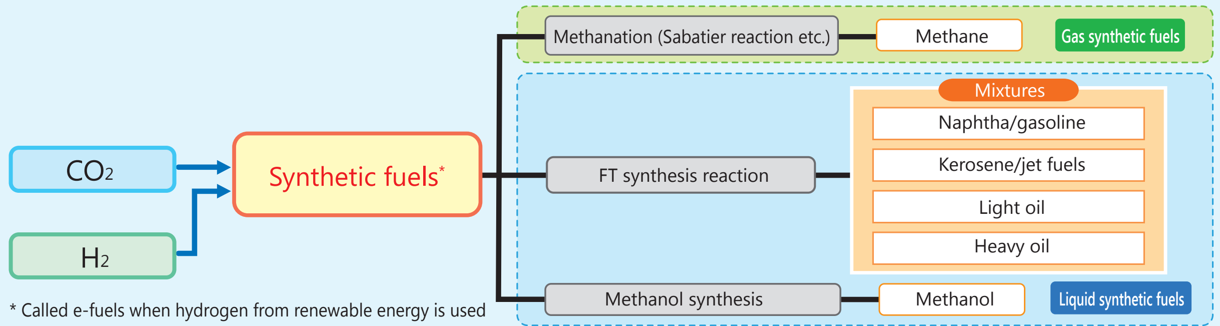
Effective use of CO_2: CCU

As a method of reducing CO_2, CCU*, a technology that captures and utilizes CO_2 emitted from power plants, factories, etc. as well as CO_2 in the air, is attracting attention. If this technology is put into practical use, it will allow the manufacturing of products, including carbon-neutral synthetic fuels and chemicals, from hydrogen and captured CO_2.

* Carbon dioxide Capture and Utilization

● Synthetic fuels

Produced by synthesizing CO_2 and hydrogen, synthetic fuels are also called artificial crude oil and are expected to be used in a broad range of applications, such as fuels for automobiles, aircraft, and ships, and heat utilization.



* Called e-fuels when hydrogen from renewable energy is used

Source: Website of the Agency for Natural Resources and Energy (https://www.enecho.meti.go.jp/about/special/johoteikyo/gosei_nenryo.html)

• Synthetic methane (methanation) * Gas fuel

The utilization of CO_2-free hydrogen will help contribute to making gases carbon neutral. Introducing synthetic methane into city gas pipes will allow existing infrastructure and equipment to be utilized.

Synthetic methane also has potential as a hydrogen carrier.

• e-fuel * Liquid fuel

It can be used as a substitute for gasoline etc. to help utilize existing infrastructure.

Its advantages include low sulfur and heavy metal content and higher energy density than gas fuels.

Imagined Community with Green Hydrogen in 2050

By 2050, Green Hydrogen will be utilized in all fields.

* Applications under development are also included.

COLUMN

Hydrogen: Old yet New Energy

In 1766, UK chemist Henry Cavendish found that a piece of metal reacting with sulfuric or hydrochloric acid produced a gas that was lighter and more flammable than air. This was the discovery of hydrogen.

In 1839, Sir William Grove of the UK succeeded in an experiment of power generation using fuel cells.

The mechanism for extracting electrical energy from the chemical reaction between hydrogen and oxygen was the prototype of present-day fuel cells, but it was overshadowed by the evolution of steam engines and was not put into practical use.

Use as life infrastructure

Hydrogen was eventually used in real life as power and fuel.

● Charcoal-powered cars

Long before fuel cell vehicles, there were cars that used hydrogen as part of their power. They were charcoal-powered cars fueled by gases, including carbon monoxide and hydrogen, generated through the incomplete combustion of charcoal and firewood.

They were introduced in Japan due to the shortage of gasoline etc. during the World War II, but they used fuels of low quality and required frequent maintenance. Once the supply of gasoline recovered, they fell into disuse.

Charcoal-powered cars

© Bureau of Transportation, Tokyo Metropolitan Government

● Syngas

Gas lights were installed in part of Japan during the civilization and enlightenment period. Syngas used for them, such as carbon monoxide and hydrogen, was produced by letting steam react with high-temperature coal etc.

Syngas was used for lighting and eventually used as a fuel for cooking and other purposes. Although it became widespread at home, syngas has been replaced by natural gas, which has a high calorific value and is environmentally friendly.

Gas light

© Tokyo Gas "Gas Museum"

Latest technology and hydrogen

Hydrogen has become indispensable in cutting-edge fields.

● Rockets

Space exploration has endless possibilities for the future development from the perspective of humankind. Liquid hydrogen, which has excellent specific impulse (fuel efficiency of rockets), is used as fuel for launching a space rocket required for transportation to outer space. The "H" in the celebrated H-IIA rocket stands for hydrogen.

H-IIA rocket

© JAXA

Having been used for a long period of time, hydrogen is well positioned as an energy source for the future.

Chapter 3

DIRECTION OF ACTIONS TOWARD A 2030 CARBON HALF

To achieve a decarbonized society by 2050, actions taken in the period leading up to the milestone marker of 2030 are extremely important.

How should we expand hydrogen energy toward 2030?

This chapter summarizes the direction of TMG's efforts.

Chapter 3 1. Direction of Actions toward a 2030 Carbon Half (Broad Outline)

The previous chapter described TMG's visions for how hydrogen will be used in a decarbonized society in 2050.

This chapter describes the direction of actions toward 2030 to achieve the visions.

The 10 years up to 2030 are extremely important

According to the Special Report on Global Warming of 1.5°C of IPCC (Intergovernmental Panel on Climate Change), limiting global average temperature rise to 1.5°C requires global CO_2 emissions to be approximately halved by 2030 and net zero by around 2050.

Actions taken during the next decade up to 2030 are extremely important and now is the last chance. To accelerate and strengthen its actions, TMG announced "Carbon Half," a plan to halve GHG emissions by 2030.

	2030 targets
Reduction of GHG emissions in Tokyo compared to 2000	50%
Reduction of energy consumption in Tokyo compared to 2000	50%
Percentage of power generated by renewable energy	Approx. 50%

Building the foundation for the use of Green Hydrogen

TMG will accelerate the development of hydrogen initiatives toward a 2030 Carbon Half.

For the full use of Green Hydrogen in the future, it is necessary to accumulate cases of utilization in Tokyo from this point going forward.

It is also essential to analyze factors that hinder the spread of Green Hydrogen, take measures to solve them, and build a foundation for its use. For Gray Hydrogen already in use, it is important to encourage substitution with lower-carbon hydrogen whenever possible.

Section 2 of this chapter describes the direction of TMG's efforts for the spread of Green Hydrogen.

Expanding the demand for hydrogen and accelerating the social implementation of hydrogen energy

As described in the previous chapter, it is important to first expand the demand for hydrogen and accelerate the social implementation of hydrogen energy toward the spread of Green Hydrogen.

In terms of creating the demand for hydrogen, it is necessary to utilize hydrogen not only in the transport, commercial, and residential fields, which have begun to introduce it, but also in other fields, such as the industrial and power generation fields. This requires further cooperation with related businesses.

Section 3 of this chapter describes the direction of efforts for the utilization of hydrogen in the transport field, which is ahead in the implementation, and Section 4 describes the direction of efforts for hydrogen utilization in other fields.

Holding of the Tokyo Hydrogen Initiative Meeting

In December 2020, TMG held the Tokyo Hydrogen Initiative Meeting, where the Governor encouraged businesses developing hydrogen businesses at home and abroad to make further efforts to expand the use of hydrogen in Tokyo and the metropolitan area and called for cooperation for the further social implementation of hydrogen technology. Taking this online meeting as an opportunity, we will further collaborate with hydrogen-related businesses to expand the use of hydrogen.

Direction of actions toward 2030 (broad outline)

In order to realize the Visions for 2050 shown in the previous chapter, we will promote our efforts considering the spread of hydrogen energy in the initial stage (until around 2025) and the medium term (until around 2030) also shown in the previous chapter as a milestone.

To that end, the direction of actions toward 2030 (broad outline) is put into the following scheme:

Visions for 2050 — **Realizing a decarbonized society** — Chapter 2 — Outlook of initial stage to medium term (until around 2030)

● **Full use of Green Hydrogen in all fields**
- Green Hydrogen playing an active role in supporting the massive introduction and supply of renewable energy ······ The foundation for the use of Green Hydrogen to be built

● **Green Hydrogen contributing to decarbonization in various fields**
- Contribution to decarbonization in the transport field ······ Hydrogen utilized for passenger cars, buses, trucks, ships, etc.
- Contribution to decarbonization in the power generation, industrial, commercial, and residential fields ······ Expanded use of fuel cells, start of introduction of hydrogen power generation and methanation with focus on supply chain construction

Actions toward 2030 — **Realizing "Carbon Half"** — Chapter 3

● **Building the foundation for the use of Green Hydrogen**
- Broader use of Green Hydrogen ······ Building the foundation for the use of Green Hydrogen through efforts to reduce costs and evaluate/utilize environmental values

● **Expansion of demand for hydrogen and social implementation of hydrogen in various fields**
- Expansion of hydrogen use in the transport field ······ Expanded introduction of fuel cell vehicles and buses; Early implementation of trucks and other large commercial vehicles; Further installation of hydrogen stations; Promotion of utilization for transportation means other than cars, such as ships
- Expansion of hydrogen use in various fields ······ Expanded use of fuel cells, promotion of introduction in the power generation, industrial, and other fields

2022

2. Broader Use of Green Hydrogen

As hydrogen does not emit CO_2 when used but Gray Hydrogen from fossil fuels emits CO_2 during production, it is important to reduce these CO_2 emissions in the future.

It is expected that the foundation for the use of Green Hydrogen will be established by around 2030 as described in Chapter 2. To this end, TMG will accumulate cases of introducing Green Hydrogen and promote efforts to reduce production costs and evaluate/utilize environmental values.

1 Status quo and challenges

▶ Importance of promoting the utilization of Green Hydrogen

TMG is supporting the introduction of Green Hydrogen through a subsidy program to promote the utilization by businesses and local governments in Tokyo.

Most of the hydrogen currently produced in Japan and the rest of the world is Gray Hydrogen from fossil fuels. Only a small number of facilities are using Green Hydrogen in Tokyo as well, posing a need to accumulate such cases in the future.

▶ Challenges for promoting the use of Green Hydrogen

To promote the use of Green Hydrogen, it is necessary to solve several challenges:

(1) Production costs

The production costs of Green Hydrogen are high at present and need to be reduced toward full use.

(2) Awareness of environmental superiority

There is not enough understanding of the different methods for producing hydrogen (gray, blue, green) and the environmental superiority of Green Hydrogen over Gray and Blue Hydrogen.

(3) Evaluation of environmental values

The environmental values of Green Hydrogen have not been fully evaluated, and as a result there has been little incentive for businesses to actively select Green Hydrogen.

(4) Production and procurement of Green Hydrogen

In order to produce and procure sufficient Green Hydrogen in Tokyo, it is necessary to consider the utilization of renewable energy from other regions.

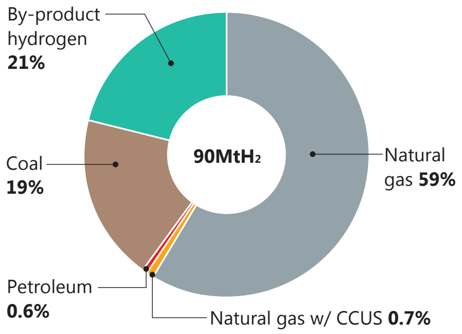
(5) Establishment of energy management technology

To let Green Hydrogen fully fulfill its role as a means of effectively using renewable energy, we need appropriate energy management, such as balancing the supply and demand for renewable power, which suffers large output fluctuations, across power grids.

Case of introduction through a subsidy program

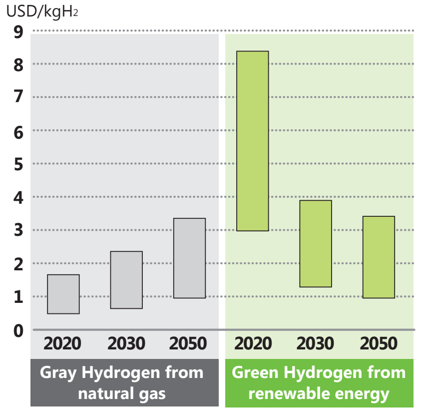
© Toshiba Energy Systems & Solutions Corporation

Hydrogen production in the world in 2020



Source: Global Hydrogen Review 2021, IEA

Production costs of hydrogen



Source: Global Hydrogen Review 2021, IEA

Core technology for Green Hydrogen production: Electrolysis of water

It is a well-known principle that hydrogen and oxygen are generated when electricity is passed through water.

The water electrolysis method is used for producing Green Hydrogen as no CO_2 is generated at the production stage through the combination with renewable power. A variety of studies are underway to reduce costs and improve efficiency of the technology.

Research for cost reduction and higher efficiency:

- Increasing the size of a water electrolyzer to enable mass production of hydrogen
- Using alternative materials for expensive precious metal components
- Electrolysis of high-temperature steam to produce hydrogen with less electrical energy

One of the largest water electrolyzers in the world at the Fukushima Hydrogen Energy Research Field

© NEDO (New Energy and Industrial Technology Development Organization)

2 Direction of policies

▶ Promoting the building of the foundation for the use of Green Hydrogen

Build the foundation for the full use of Green Hydrogen from 2030 onwards by accumulating cases of introducing Green Hydrogen and promoting efforts to reduce production costs and evaluate/utilize environmental values

3 Efforts for the future

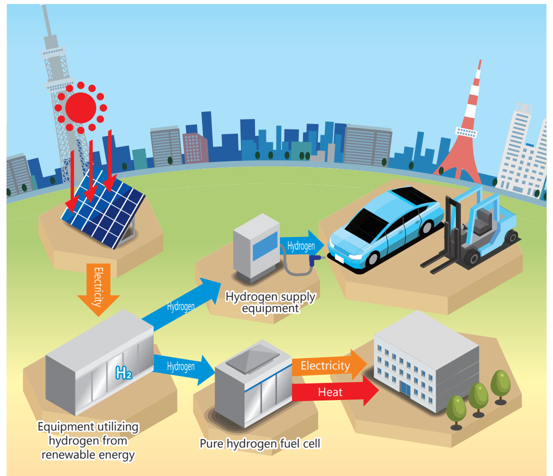
▶ Cost reduction and efficiency improvement of hydrogen production equipment Promotion of its introduction in Tokyo

TMG will continue to support the introduction of water electrolyzers and pure hydrogen fuel cells, thereby accumulating cases of utilizing Green Hydrogen at facilities in Tokyo, and promote cost reduction and efficiency improvement of water electrolyzers, which constitute the core technology for Green Hydrogen production.

▶ PR on environmental superiority of Green Hydrogen

TMG will actively publicize the cases of utilization at the Tokyo 2020 Games and Green Hydrogen utilization facilities in Tokyo on its website and events.

In collaboration with Fukushima Prefecture and research institutes, we will utilize Green Hydrogen produced in the prefecture in Tokyo and publicize the utilization.



▶ Consideration of incentives for evaluation and utilization of environmental values

It is expected that the cost of Green Hydrogen will decrease due to the reduction in the production costs of renewable power. At the same time, it is also important to encourage the further reduction in Green Hydrogen costs by means of policies by promoting the introduction of Green Hydrogen through the evaluation of its environmental values.

To that end, TMG will consider efforts for the evaluation and utilization of environmental values, which will include strengthening incentives according to the greening of hydrogen (manufacturing source) used in the introduction support program of TMG and promoting the early introduction of the certification or crediting of Green Hydrogen. We will request the national government to establish the evaluation of environmental values and set up incentive measures and mechanisms, including regulatory methods, such as the introduction of carbon pricing.

TMG will also consider evaluating the introduction of Green Hydrogen utilization equipment by means of its environment-related programs.

Utilization of hydrogen at the Tokyo 2020 Games

At the Tokyo 2020 Games, hydrogen was used for the first time in the history of the Games for the Olympic cauldron and some of the torches for relaying the Olympic flame.

Hydrogen was also used at the Relaxation House and in some of the residential buildings in the Olympic Village. Such hydrogen included that produced with renewable energy in Fukushima Prefecture. We will aggressively provide information on these cases of utilization as a legacy of the Games.

Relaxation House in the Olympic Village

Olympic cauldron

© Tokyo 2020/Uta MUKUO

2. Broader Use of Green Hydrogen

▶ Consideration of production and procurement methods of Green Hydrogen using renewable energy from other regions

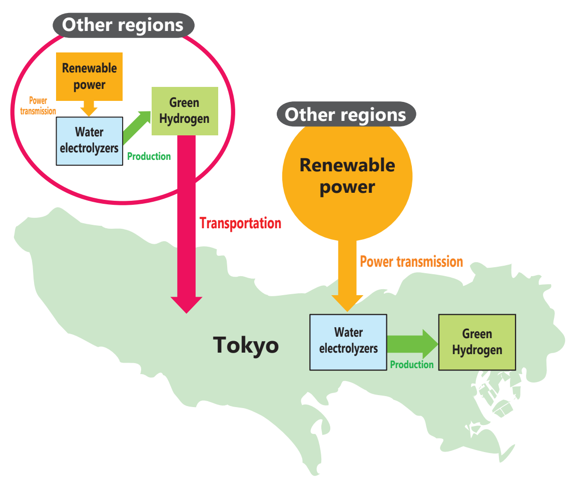
It is important to expand the use of Green Hydrogen using renewable energy in Tokyo. On the other hand, as mentioned above, in order to produce and procure sufficient Green Hydrogen in Tokyo, it is necessary to consider the utilization of renewable energy from other regions.

Such considerations may include using renewable power from other regions to produce Green Hydrogen in Tokyo, and transporting Green Hydrogen produced in other regions to Tokyo.

In addition, transactions using the environmental values of hydrogen will also be possible.

To increase the supply of Green Hydrogen as the demand for hydrogen is expected to grow in the future, TMG will work to expand the utilization of renewable energy from other regions, make the above-mentioned efforts for the evaluation and utilization of environmental values of hydrogen, and consider more effective methods, such as encouraging the national government to establish the evaluation of environmental values.

Image of production and procurement of Green Hydrogen using renewable energy from other regions

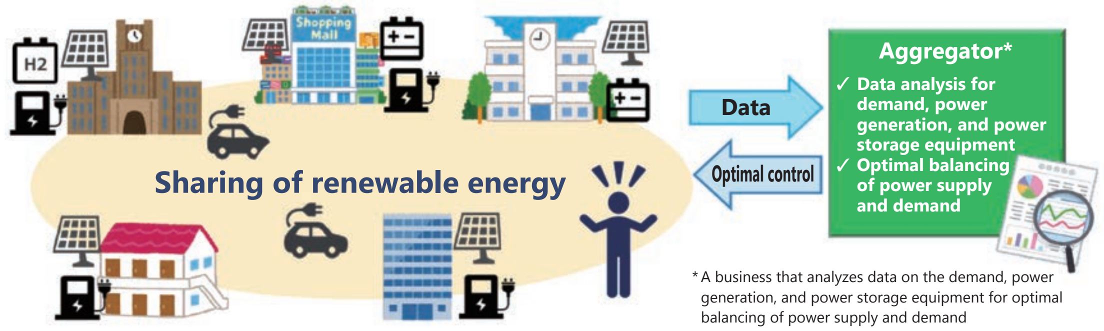


▶ Consideration of energy management through a promotion project and research

In the Minami-Osawa district of Hachioji City, TMG has been carrying out the Regional Renewable Energy Sharing Promotion Project that efficiently uses regional renewable energy by balancing power supply and demand, in anticipation of the era of the massive introduction and supply of renewable energy. We will effectively operate the Green Hydrogen utilization equipment installed through the project, deepening our consideration and exploration.

In addition, the Tokyo Metropolitan Research Institute for Environmental Protection is conducting research aimed at efficient energy use at buildings that utilize hydrogen.

Image of sharing of regional renewable energy



* A business that analyzes data on the demand, power generation, and power storage equipment for optimal balancing of power supply and demand

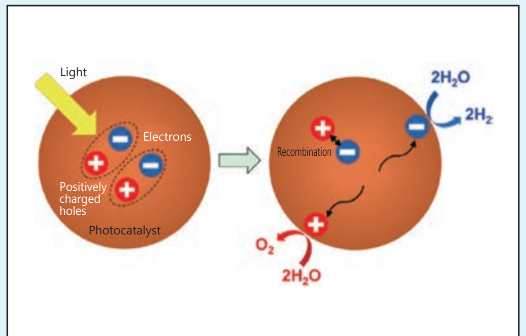
Innovative technology: Photocatalytic hydrogen production

A substance that accelerates a chemical reaction is called a catalyst and is widely used in the chemical industry etc. A catalyst that absorbs sunlight and exhibits catalytic action is a photocatalyst and is known to cause a reaction, such as splitting water into hydrogen and oxygen.

Principle: When sunlight is absorbed, negatively charged electrons and positively charged holes are generated inside a photocatalyst. They move to the surface of the photocatalyst and cause redox reactions with water to generate hydrogen and oxygen.

Unlike electrolysis, photocatalysts can produce hydrogen directly from sunlight. Since CO_2 is not generated, hydrogen production using a photocatalyst is anticipated to be one of the ways to produce Green Hydrogen in the future. With the aim of putting it into practical use, research is underway all over the world to meet a challenge at present: the improvement of its efficiency.

Principle of hydrogen generation with a photocatalyst



© National Institute of Advanced Industrial Science and Technology

COLUMN

Green Hydrogen Production Projects Start to Move in the World

As hydrogen-related efforts have been accelerating around the world in recent years, projects to produce Green Hydrogen have started to gather momentum.

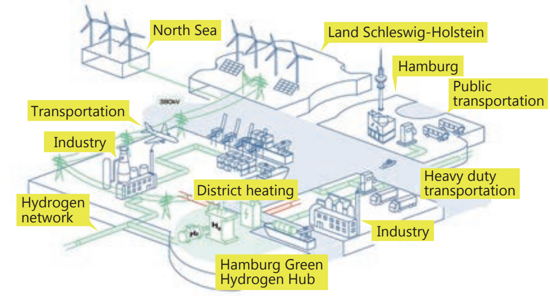
Overseas

● Germany

Three businesses including a Japanese heavy industry manufacturer are studying the feasibility of a Green Hydrogen hub (production and supply project) that utilizes the site of a former thermal power plant.

[Hydrogen production equipment of 100 MW]

Schematic view of Green Hydrogen hub in Germany



© Mitsubishi Heavy Industries, Ltd.

● Netherlands

European oil majors are promoting integrated development projects that combine, for example, offshore wind power generation and Green Hydrogen production.

[Offshore wind power generation of 759 MW as of 2023]

● Australia

An Australian electric power company and a Japanese energy business are conducting research into the commercialization of a project to produce and liquefy a large amount of Green Hydrogen and export it to Japan.

[Green Hydrogen production of 800 tonnes/day or more from 2031]

● Saudi Arabia

Energy businesses in the United States and Saudi Arabia are planning to build a Green Hydrogen production facility with the world's top-class hydrogen supply capacity.

[Solar and wind power generation of 4 GW/Green Hydrogen production of 650 tonnes/day]

Japan

● Namie Town, Fukushima Prefecture

In an experimental study project* by a Japanese heavy electric manufacturer, a hydrogen production research facility has been constructed in Namie Town, Fukushima Prefecture, for testing the production of Green Hydrogen with a large water electrolyzer.

[Solar power generation of 20 MW/Hydrogen production equipment of 10 MW]

Hydrogen production research facility

© NEDO (New Energy and Industrial Technology Development Organization)

● Kofu City, Yamanashi Prefecture

In an experimental study project* by the Yamanashi Prefectural Enterprise Bureau, a system for producing and testing Green Hydrogen has been constructed at the Yonekurayama Electric Power Storage Technology Research Site in Kofu City, Yamanashi Prefecture, to test the feasibility of larger or modular hydrogen production equipment.

[Solar power generation of 10 MW/Hydrogen production equipment of 2.3 MW]

Yonekurayama Electric Power Storage Technology Research Site

© Yamanashi Prefectural Enterprise Bureau

● Kokonoe Town, Kusu District, Oita Prefecture

A Japanese general contractor has built a plant in Kokonoe Town, Kusu District, Oita Prefecture, in order to produce Green Hydrogen using geothermal power generation and verify a series of processes leading up to supply to customers.

[Geothermal power generation of 125 kW/Green Hydrogen production of 10 Nm^3/h]

Green Hydrogen production verification plant

© Obayashi Corporation

Other efforts are underway in different regions to produce hydrogen from livestock manure and other raw materials.

* Implemented as a project of NEDO (New Energy and Industrial Technology Development Organization)

Chapter 3 3. Expansion of Hydrogen Use in the Transport Field

As described in Chapter 2, hydrogen is expected to be utilized for transportation equipment, such as large vehicles and ships, in the transport field by around 2030. To this end, TMG will promote, first of all, the decarbonization of automobiles, which account for approximately 80% of CO_2 emissions in the transport field.

Fuel cell vehicles have the advantage of not emitting any CO_2 during driving, being suitable for large vehicles and long-distance driving, and completing filling hydrogen within a short time. Therefore, we will further expand the introduction of fuel cell vehicles (passenger cars) and buses, and promote the early implementation of commercial fuel cell vehicles, such as fuel cell trucks.

As the spread of these vehicles will lead to technological innovations and cost reductions in fuel cells, the next step will be to encourage the use of hydrogen in transportation means other than automobiles, such as ships.

1 Status quo and challenges

Broader use of fuel cell vehicles

TMG supports the introduction of fuel cell vehicles and buses, which are familiar means of transportation and are being developed for mass production.

We are also developing fuel cell garbage trucks and carrying out their trial operation in collaboration with universities, municipalities, etc.

■ Introduction of fuel cell vehicles

	Result as of the end of Feb. 2022	Target for 2030
Qty	1,341* * Subsidized	Eliminating the sale of new gasoline passenger cars

■ Introduction of fuel cell buses

	Result as of the end of Feb. 2022	Target for 2030
Qty	93	300 or more zero emission buses

Fuel cell vehicle (FCV)

© Toyota Motor Corporation

Fuel cell bus (FC bus)

Challenges for the broader use of fuel cell vehicles

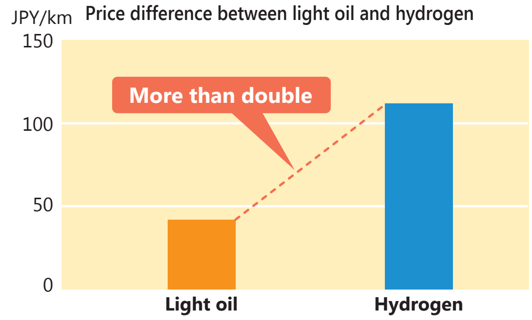
Fuel cell vehicles (passenger cars) are being gradually introduced. However, only a few manufacturers sell them worldwide and their types are limited due to their advanced technology, and the number of those introduced has not reached the target set in FY 2014. It is hoped that vehicle types will be expanded to sport utility vehicles (SUVs) and minivans, for example, which will meet consumer needs.

As fuel cell buses are more expensive than diesel buses, and the difference in fuel costs between hydrogen and light oil is large, a further reduction in vehicle prices and fuel costs is necessary for their autonomous spread.

For commercial fuel cell vehicles other than buses, private businesses are verifying the feasibility of driving fuel cell trucks, but require support for their implementation.

In addition to vehicles with fuel cells, the use of hydrogen and synthetic fuels (e-fuels) for internal combustion engine vehicles may be an option for decarbonization in the transport field.

Price difference between light oil and hydrogen



* Light oil price is the average of truck delivery prices for major consumers in FY 2020.
Source: Website of the Agency for Natural Resources and Energy
* Hydrogen price is the average of sales prices at hydrogen refueling stations in Tokyo.

Fuel cell trucks (FC trucks)

© Toyota Motor Corporation

Installation of hydrogen refueling stations supporting fuel cell vehicles

In order to expand the use of fuel cell vehicles, it is necessary to create an environment where users can find hydrogen refueling stations nearby and fill up on hydrogen with peace of mind at any time.

TMG is decisively promoting the installation of hydrogen refueling stations by providing a wide range of subsidies for their installation and operation costs.

As of the end of FY 2021, there are 23 hydrogen refueling stations in Tokyo including one under installation, of which 9 can fill fuel cell buses as well.

Challenges for expanding the installation of hydrogen refueling stations

Installation is progressing mainly in the coastal area, but there is still a shortage of hydrogen refueling stations in the inland area of the 23 wards, the Tama area, etc.

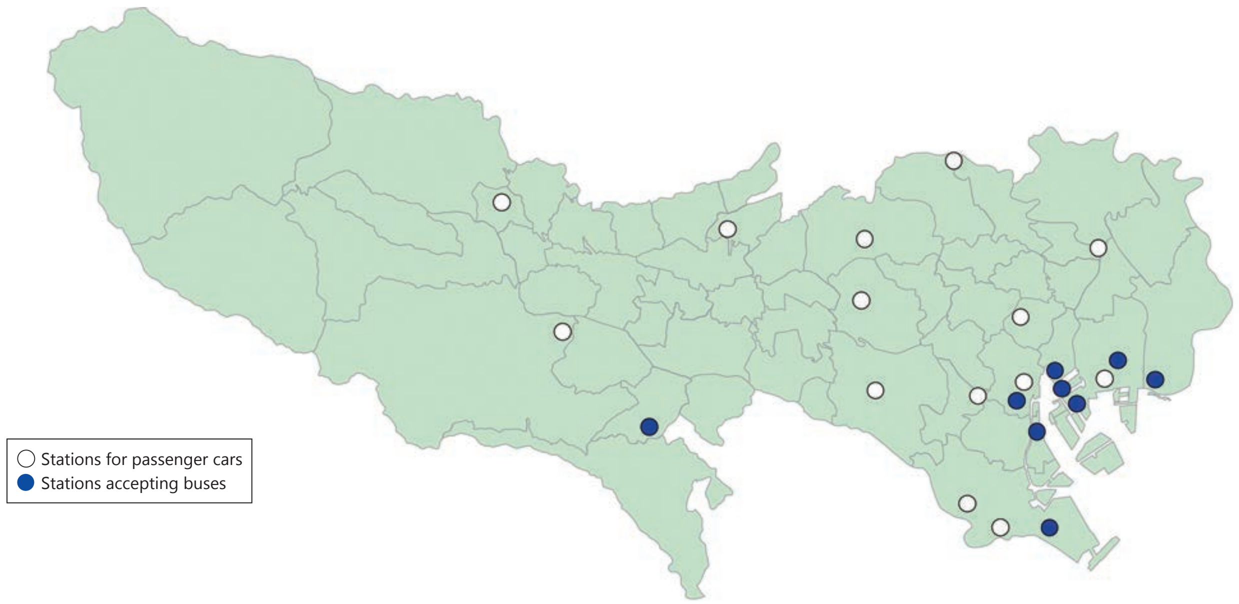
Partly because of the existence of strict laws and regulations, their installation and operation costs are higher than those of gas stations. Such sites cannot be easily secured in Tokyo as they need a large plot of land.

It is also important to create an environment where existing gas stations and small and medium-sized or local businesses can participate in the business.

To improve the business viability of hydrogen refueling stations, it is necessary to accelerate the introduction of fuel cell vehicles other than passenger cars and increase the demand for hydrogen.

Currently, some hydrogen refueling stations use by-product hydrogen or that from plastic waste as hydrogen for filling, but most of them use Gray Hydrogen reformed from fossil fuels, which will need to be replaced with Green Hydrogen in the future.

Installation of hydrogen refueling stations in Tokyo
(23 stations installed as of the end of FY 2021 including one under installation)



2 Direction of policies

Further expansion of the demand for hydrogen focusing on the introduction of commercial fuel cell vehicles

- Further expand the use of hydrogen for automobiles by expanding the introduction of fuel cell vehicles (passenger cars) and fuel cell buses as well as realizing the early implementation of trucks and other large commercial fuel cell vehicles
- Enhance a hydrogen filling environment by adding a hydrogen refueling station to an existing gas station and installing hydrogen refueling stations that meet the demand for fuel cell buses and trucks
- Provide support for securing the business viability of hydrogen refueling stations that were installed ahead of others

Encouraging the use of hydrogen in transportation means other than automobiles, such as ships, through technology development and reduced hydrogen prices as a result of the spread of fuel cell vehicles

Chapter 3 3. Expansion of Hydrogen Use in the Transport Field

3 Efforts for the future

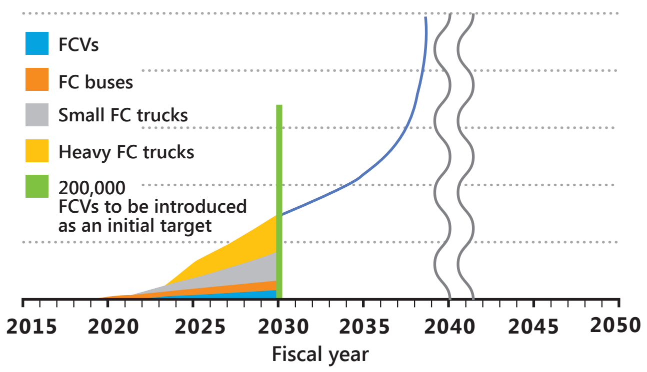
▶ Developing efforts to further expand the use of hydrogen by automobiles

To increase the applications of fuel cell vehicles (passenger cars), TMG will work to expand their use as service vehicles, such as rental or shared cars.

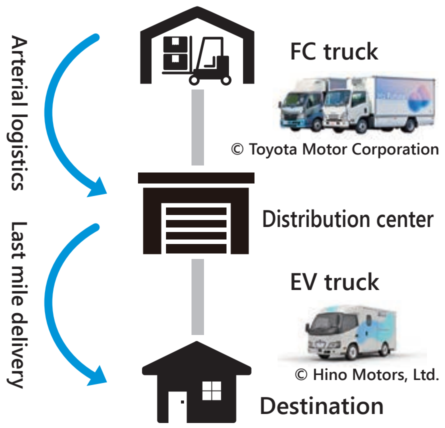
We will ensure the broader use of fuel cell buses by providing incentives according to the number of those introduced and carrying out support measures etc. to cover part of hydrogen filling prices which are higher than those of light oil.

For other commercial vehicles with high hydrogen utilization potential, we will take support measures according to the needs and development status of vehicle types, with a view toward early implementation.

Expected hydrogen demand from automobiles



Logistics center in Tokyo



Promoting early introduction of fuel cell trucks under development

Fuel cell garbage truck

Fuel cell forklift

© Toyota Industries Corporation

Promoting early introduction in collaboration with manufacturers

▶ Enhancing the hydrogen filling environment indispensable for the spread of fuel cell vehicles

Further relaxation of restrictions and expansion of support measures

TMG will install hydrogen refueling stations accepting large fuel cell vehicles at appropriate locations for the broader use of hydrogen in terms of both supply and demand.

For that purpose, we will decisively require the national government to make existing regulations for hydrogen refueling stations similar to those for gas stations, which may include further relaxing the regulation for the separation distance between hydrogen-related equipment and public roads as well as simplifying the legal inspection that causes higher costs.

We will encourage the expanded installation of hydrogen refueling stations from all angles and aim to more than double the number of stations installed in Tokyo by covering part of installation and operation costs, actively utilizing TMG-owned land, raising subsidy rates for land rent to mitigate higher land use costs in Tokyo, and supporting the installation of small hydrogen refueling stations that are expected to be located on narrow plots of land.

Bus-capable hydrogen refueling station

© Keio Dentetsu Bus Co., Ltd.

Support for multi-energy stations and bulk filling

It is important to utilize existing gas stations in Tokyo where large plots of land cannot be acquired easily. To help them act as an environment-friendly local energy supply base, TMG will work to convert existing gas stations into multi-energy stations by encouraging the installation of a hydrogen refueling station or fast chargers and incorporating rental or shared ZEVs into the sites.

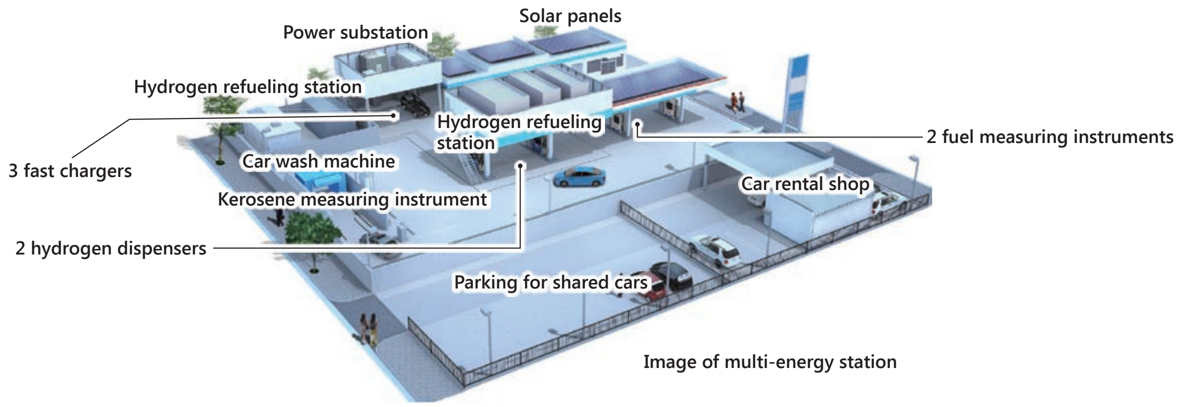


Image of multi-energy station

Looking ahead to the establishment of filling standards for large fuel cell vehicles currently verified by the national government, TMG will promote the installation of hydrogen refueling stations capable of bulk filling for heavy trucks.

We will consider providing support for making existing hydrogen refueling stations capable of filling large vehicles, improving their functions, and replacing their equipment.

Decarbonization of hydrogen refueling stations

To decarbonize hydrogen filled at hydrogen refueling stations, we will consider incentives or the evaluation of efforts to decarbonize hydrogen refueling stations, such as producing Green Hydrogen through the water electrolysis method using solar power and other renewable energy.

▶ Promoting the commercialization of hydrogen fuel ships

The use of hydrogen in the transport field is not limited to automobiles. It is expected to be utilized for ships and aircraft in the future.

With the tightening of emission control regulations by the International Maritime Organization (IMO), fuel for ships is being replaced by alternatives with less environmental load. Hydrogen-fueled ships are expected to be introduced as one form of zero-emission ships in the future. TMG is encouraging the commercialization and early service of hydrogen fuel ships by introducing an incentive program that exempts them from port entry fees.

Hydrogen engine cars

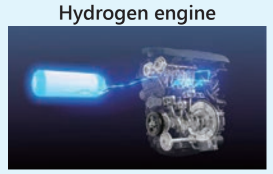
Commercially available automobiles that drive on hydrogen are called fuel cell vehicles because they drive by turning a motor with electricity generated by a chemical reaction of hydrogen in a fuel cell.

On the other hand, the development of hydrogen engine cars, which directly burn hydrogen instead of gasoline to generate energy for driving, is underway. Hydrogen engine cars can utilize conventional engine technology unlike fuel cell vehicles.

Some hydrogen engine cars under development, which have not been commercialized, participate in races.

Consideration of using hydrogen engines for motorcycles has also started.

Hydrogen engine



© Toyota Motor Corporation

Vehicle in a race

© Toyota Motor Corporation

Utilization of hydrogen for rail transport

To promote the decarbonization of railways that serve as a mass transportation facility, a Japanese railroad company, in collaboration with an automobile manufacturer, is developing a railroad car equipped with a hybrid system fueled by hydrogen and powered by fuel cells and storage batteries.

The verification test was started in March 2022.

Fuel cell railroad cars

© East Japan Railway Company

4. Expansion of Hydrogen Use in Various Fields

As described in Chapter 2, hydrogen is expected to contribute to decarbonization in different fields by around 2030, such as fuel for power generation and heat demand in the industrial, commercial, and residential fields.

To this end, the initial requirement is expanding the use of fuel cells etc., which will then enable us to reduce CO_2 emissions in the commercial and residential fields, encourage development for introducing hydrogen in the power generation and industrial fields in the future, and expand the demand for hydrogen.

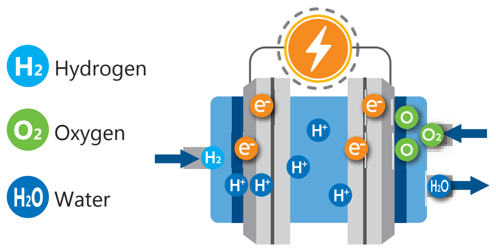
1 Status quo and challenges

Expanded use of fuel cells

Fuel cells are one of the most important technologies for the use of hydrogen, capable of extracting electricity and heat from hydrogen through electrochemical reaction. This mechanism allows highly efficient power generation, downsizing, and the use of exhaust heat.

TMG is supporting the introduction of commercially available residential fuel cells (ENE-FARM), commercial and industrial fuel cells, and pure hydrogen fuel cells.

How a fuel cell works



■ Installation of residential fuel cells

	Result as of the end of Feb. 2022	**Target for 2030**
Qty	Approx. 67,000	1 million

■ Installation of commercial and industrial fuel cells

	Result as of the end of Feb. 2022	**Target for 2030**
Wattage	Approx. 2.5 MW	30 MW

Challenges for the expanded use of fuel cells

Further price reductions are necessary for the broader use of fuel cells.

Fuel cells that reform city gas to produce hydrogen have an issue in that CO_2 is generated during reforming.

Versatile use of fuel cells, combustion of hydrogen for use in various fields

Fuel cells are used for residential fuel cells (ENE-FARM) and fuel cell vehicles, and fuel cell systems used here have a potential to be applied to drones, agricultural machinery, construction machinery, small ships, port equipment, and many others. Therefore, their applications should be expanded in the future accordingly.

In addition to the utilization of fuel cells, hydrogen can be directly burned to generate energy, creating a need to promote development toward practical use in a range of fields, including power generation, large ships, aircraft, and industrial processes.

2 Direction of policies

▶ Encouraging the use of hydrogen for fuel cells and many other purposes to expand the demand for hydrogen

- Continue supporting the introduction of fuel cells, encourage the spread of and price reductions in applicable equipment, and promote the decarbonization of fuel itself
- Further cooperate with related businesses and the national government to promote the utilization of hydrogen in a variety of fields

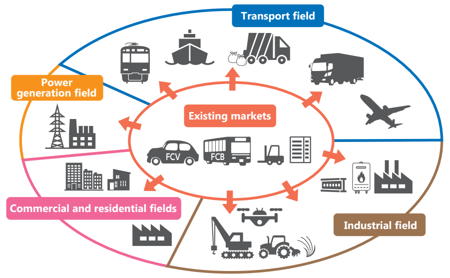
3 Efforts for the future

▶ Continuing support for the introduction of fuel cells

TMG will continue supporting the introduction of residential, commercial, and industrial fuel cells, ensure their expanded use, and promote technology development that will lead to reduced prices, more efficient power generation, and downsizing.

In order to solve issues with equipment fueled by hydrogen reformed from city gas, we will encourage the early introduction of methanation (Section 3(3), Chapter 2) and CCUS at the place of use. We will also continue to promote the broader use of pure hydrogen fuel cells.

▶ Promoting the utilization of hydrogen in different fields (versatile use of fuel cells, combustion of hydrogen for use in various fields)



As for the versatile use of fuel cells and the combustion of hydrogen for use in various fields, TMG will cooperate with related businesses, the national government, and local governments for the promotion of practical use, promote introduction according to the trends in technology development, actively provide information on the latest technology, and request the national government to support technology development.

We will utilize the Sustainable Energy Fund to promote the installation of clean energy bases, including hydrogen-related business.

▶ Urban development as a legacy of the Tokyo 2020 Games

At the Tokyo 2020 Games, hydrogen was used to supply power to the Relaxation House for athletes and for other purposes.

In the redevelopment district of Harumi, where the Olympic Village was located during the Tokyo 2020 Games, hydrogen supply to blocks through pipelines is planned, which will be in practical use for the first time in Japan. We will also promote the utilization of hydrogen through urban development in the future.

Image of Harumi redevelopment district

© Designated Builder for Class 1 Urban Redevelopment Project in Harumi 5-Chome West District

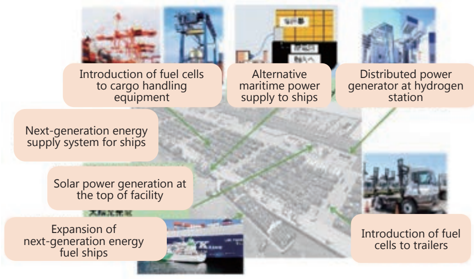
▶ Efforts in the coastal area

The following efforts will be made in the coastal area as it is expected to contribute to a decarbonized society.

Based on a public-private partnership at the Port of Tokyo, TMG will formulate a carbon-neutral port building plan to work on decarbonization by means of hydrogen.

We will promote the spread of hydrogen energy among private businesses by building a model for the utilization of hydrogen energy at buildings in the Tokyo Waterfront City.

Image of carbon neutral port



Source: Future Tokyo: Tokyo's Long-Term Strategy Upgrade 2022

Examples of versatile use of hydrogen

● Fuel cell power generator

Fuel cells with high power generation capacity are also considered for use in portable power generators. If such an application is realized, they will be used in a wide range of fields, such as civil engineering and construction sites and power supply for daily life needs in the event of a disaster.

FC modules

As there are efforts to package a fuel cell system and sell it as an FC module that is easily available, it is expected that fuel cells will be used for many applications in various industries in the future.

Fuel-cell-based portable hydrogen power generator

© Denyo Co., Ltd.

FC module

© Toyota Motor Corporation

● Hydrogen fuel boiler

Since hydrogen is also expected to be used through combustion, several businesses are developing small hydrogen boilers and bringing them to market.

While boilers fueled by hydrogen alone do not emit CO_2 during combustion, the equipment that emits less nitrogen oxides (NOx) during combustion can be compatible with measures for air pollution.

Therefore, in 2021, TMG started to cover hydrogen fuel boilers for certification under the Certification Program for Small Combustion Appliances with Low NOx/CO_2*.

* A program to certify small combustion appliances that emit less NOx and CO_2 to reduce these substances emitted from such appliances

Hydrogen fuel boilers

© Miura Co., Ltd.

5. Fostering Momentum

It is expected that the social implementation of hydrogen energy will progress by around 2030 as described in Chapter 2. To this end, TMG will effectively provide information to Tokyo residents and organizations.

1 Direction of policies

▶ Developing efforts to ensure the further expansion and facilitate the understanding of hydrogen energy

- Raise awareness of a wide range of generations in collaboration with a variety of actors
- Take a continuous approach by making use of online content

2 Efforts for the future

▶ Fostering a movement in both public and private sectors

TMG has been working to raise public awareness through visual depictions of hydrogen energy since 2017 when we launched the Tokyo Hydrogen Promotion Team in cooperation with more than 100 private organizations and local governments in Tokyo. We will encourage cooperation between businesses, including support for networking among businesses, toward the social implementation of hydrogen energy.

Launch event

▶ Collaboration with other prefectures and research institutes

TMG, Fukushima Prefecture, National Institute of Advanced Industrial Science and Technology, and Tokyo Environmental Public Service Corporation have been utilizing hydrogen produced in Fukushima Prefecture in Tokyo and publicizing each other at environmental events since 2016 when we concluded an agreement to expand the use of CO_2-free hydrogen.

Furthermore, TMG and New Energy and Industrial Technology Development Organization (NEDO) have been working together to hold seminars and provide environmental learning opportunities since 2020 when we concluded an agreement for the expanded use of hydrogen energy.

During the Tokyo 2020 Games, hydrogen produced in Fukushima Prefecture using renewable energy was used at the Relaxation House and some of the residential buildings in the Olympic Village.

We will continue to collaborate in sharing technical knowledge and conducting public relations and awareness raising activities, and promote efforts for the broader use of hydrogen from renewable energy.

Hydrogen cylinder pack at Tokyo 2020 Games Olympic Village

▶ Providing information online

There are increasing opportunities to utilize online content due to the impacts of the COVID-19 pandemic. To raise public awareness of hydrogen energy, TMG provided relevant information by holding online events and seminars.

We will take a continuous approach to a wide range of generations by enhancing our website and other platforms for providing information and by regularly distributing online content on the themes of the significance of and safety measures for hydrogen as well as the latest research and new technologies related to hydrogen.

Online event for elementary school students in FY 2021

Hydrogen information center "Tokyo Hydrogen Museum"

It is a comprehensive learning facility where you can enjoy learning about invisible hydrogen and the future visions of a hydrogen powered society through a hands-on experience.

Established in 2016, it provides easy-to-understand information for all, from children to the elderly.

Hydrogen information center "Tokyo Hydrogen Museum"

© Tokyo Environmental Public Service Corporation

COLUMN

What is the demand for hydrogen as energy around 2030?

The use of hydrogen as energy is limited at present, but it has the potential to be used in a variety of fields in the future.

It is expected that the expanded demand for hydrogen in the future will encourage technology development, supply chain construction, and cost reduction, resulting in a virtuous cycle that accelerates the social implementation of hydrogen energy.

Assuming that inexpensive hydrogen will be procured in large quantities around 2030, in what fields and to what extent will hydrogen be utilized as energy?

● Fuel cell vehicles

As described in Section 2 of Chapter 2, the utilization of hydrogen is envisaged as a way to decarbonize automobiles etc.

The demand for hydrogen in 2030 in Tokyo is estimated to be **approximately 70 million Nm^3** based on the anticipated introduction of fuel cell vehicles, buses, and trucks (small and large sizes) in Tokyo.

In addition, **more demand for hydrogen is expected** as it is anticipated to be needed for a variety of transportation equipment, such as fuel cell forklifts, which have already been commercialized, garbage trucks, and ships.

● Methanation

As described in Sections 3(2) and (3) of Chapter 2, the utilization of hydrogen is expected as a way to decarbonize heat.

In its Green Growth Strategy Through Achieving Carbon Neutrality in 2050, the national government aims to increase methane synthesized by methanation up to 1% in the existing infrastructure by 2030. Based on this forecast, the amount of synthetic methane introduced is estimated to be 400 million m^3 in Japan, and the amount of hydrogen required for methanation is estimated to be 1.6 billion m^3 in Japan*.

In Tokyo, from the above values and the ratio of the final energy consumption of city gas in Tokyo to that in Japan at present, approximately 50 million m^3 of synthetic methane is expected to be introduced and the amount of hydrogen required for methanation is estimated to be **approximately 200 million m^3**.

* Materials for the 4th Meeting of Methanation Promotion Public-Private Council

● Hydrogen power generation

As described in Section 3(1) of Chapter 2, it is expected that hydrogen power generation will be put into practical use with some businesses carrying on its development.

In its Outlook for Energy Supply and Demand in FY 2030 and related materials, the national government assumes, as a prospect of use in 2030, that an international commercial supply chain for hydrogen and ammonia* will be established and hydrogen and ammonia power generation will start at a certain level. Based on the assumption, the government estimates that such power generation will account for approximately 1% of the power generation mix.

The related materials also estimate that the supply from the international supply chain to the power generation sector will consist of 300,000 tonnes (approximately 3.4 billion Nm^3*) of hydrogen and 3 million tonnes (approximately 3.9 billion Nm^3*) of ammonia in Japan.

From the ratio of the final energy consumption of electricity in Tokyo to that in Japan at present, when the above amount of hydrogen is prorated, **approximately 300 million Nm^3** of hydrogen is estimated to be used for power consumption in Tokyo with ammonia estimated as approximately 400 million Nm^3.

* Conversion to Nm^3 has been made by TMG

● Applications other than energy

In addition to the use as energy, hydrogen is used as raw material in a variety of processes of the industrial field, such as the desulfurization process of oil refining and the lipstick manufacturing process.

If you look into the manufacturing process of products around you, you may find that hydrogen is actually used as a raw material.

* The demand for hydrogen in this column is an estimate made by TMG under certain conditions and subject to change depending on prerequisites or future technological development.

Chapter 3

Hydrogen Roadmap for 2030 and 2050

TMG will promote the expansion of the demand for hydrogen and its social implementation toward a 2030 Carbon Half, and build the foundation for Green Hydrogen to become a pillar for the realization of a decarbonized society by 2050.

In light of trends in hydrogen-related technology development and market launch, we will further deepen cooperation with related businesses, the national government, and local governments to accelerate the broader use of hydrogen in terms of both supply and demand.

● Direction of TMG's efforts from initial stage to medium term • Hydrogen powered society in long-term perspective, corporate development trends, etc.

Initiatives		Initial stage (until around 2025) / Medium term (until around 2030)	Long term (until around 2050)
Supply of hydrogen	Green Hydrogen	● Accumulating cases of introducing Green Hydrogen ● Expanding introduction of hydrogen production equipment ● Building foundation for use of Green Hydrogen ● Evaluation and utilization of environmental values	• Full use of Green Hydrogen in all fields • Supporting massive introduction and supply of renewable energy
Use of hydrogen	All fields	● Expansion of demand for hydrogen and social implementation of hydrogen	• Shift to Green Hydrogen
	Transport field	● Expanding introduction of fuel cell vehicles Enhancing hydrogen filling environment ● Further expanding introduction of FCVs and FC buses ● Expanding introduction of trucks and other large commercial vehicles ● Expanding installation of hydrogen refueling stations ● Expanding use for ships	• Decarbonization in transport field • Expanding use for aircraft and other large transportation equipment
	Various fields Power generation Industrial Commercial/ residential	● Promoting spread and price reduction of hydrogen-based equipment ● Further expanding use of fuel cells ● Versatile use of fuel cells, combustion for use in various fields ● Utilizing hydrogen through urban development and efforts in the port area	• Decarbonization in various fields
		• Use for power generation	• Use for power generation • Utilization as an adjusting mechanism for renewable power
			• Use for steel making and other industries
		● Promoting decarbonization of thermal energy • Introduction of methanation	• Decarbonization of thermal energy • Spread of methanation
		● Fostering momentum in collaboration with a variety of actors	● Fostering momentum in collaboration with a variety of actors

Reference

- Green Growth Strategy towards 2050 Carbon Neutrality (2020, 2021), Ministry of Economy, Trade and Industry
- Materials for the Committee on the Green Innovation Project (2020, 2021), Industrial Structure Council, Ministry of Economy, Trade and Industry
- The 6th Strategic Energy Plan (2021), Ministry of Economy, Trade and Industry
- Outlook for Energy Supply and Demand in FY 2030 (related materials, 2021), Ministry of Economy, Trade and Industry
- Comprehensive Energy Statistics, Ministry of Economy, Trade and Industry
- Energy Consumption Statistics by Prefecture, Ministry of Economy, Trade and Industry
- Strategic Road Map for Hydrogen and Fuel Cells (2019), Ministry of Economy, Trade and Industry
- Materials for the Council for a Strategy for Hydrogen and Fuel Cells (18th to 27th meetings, 2020, 2021), Ministry of Economy, Trade and Industry
- Materials for the Methanation Promotion Public-Private Council (2021, 2022), Ministry of Economy, Trade and Industry
- Special Contents website, Ministry of Economy, Trade and Industry
- Safety Guidelines for Hydrogen Fuel Cell Ships (2021), Ministry of Land, Infrastructure, Transport and Tourism
- "Low-Carbon - What is a Hydrogen Supply Chain?" website, Ministry of the Environment
- Global Hydrogen Review 2021, IEA
- Future Outlook for the Hydrogen Utilization Market 2021, Fuji Keizai Group Co., Ltd.
- Website of Japan External Trade Organization (JETRO)
- Website of NEDO (New Energy and Industrial Technology Development Organization)
- Website of Iwatani Corporation
- Website of ENEOS Corporation
- Website of Obayashi Corporation
- Website of Kawasaki Heavy Industries, Ltd.
- Website of Chiyoda Corporation
- Website of Denyo Co., Ltd.
- Website of Toyota Motor Corporation
- Website of East Japan Railway Company
- Website of Miura Co., Ltd.
- Website of Mitsubishi Heavy Industries, Ltd.

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