Initiatives in the Hydrogen Supply Chain Aimed at Realizing a Carbon-Free Society

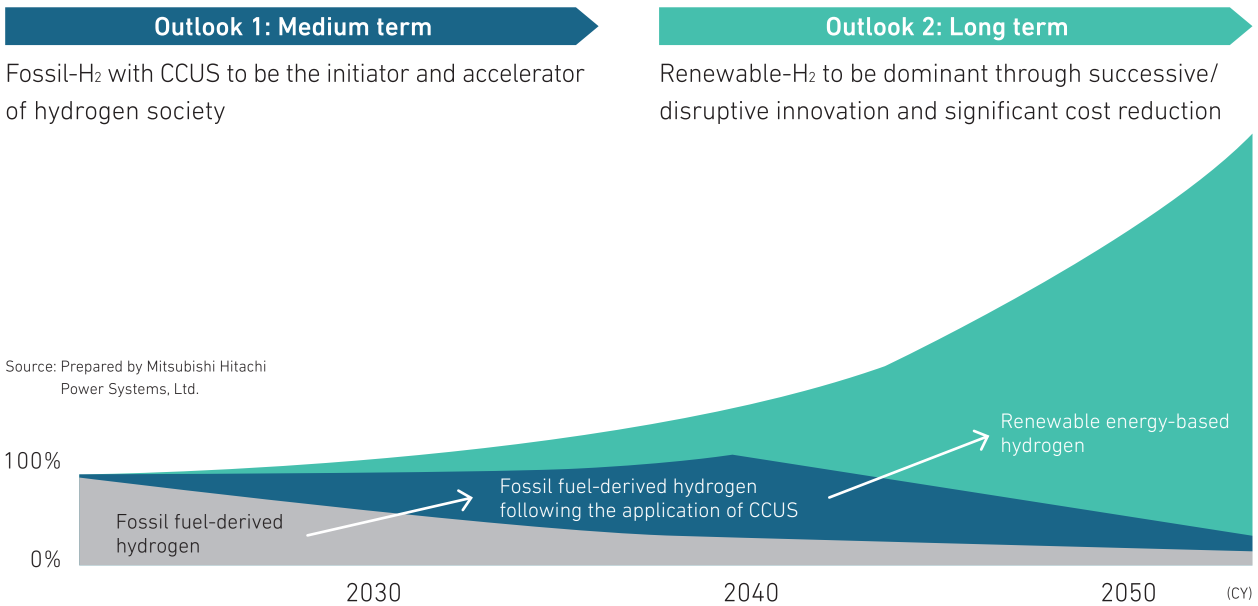
The Paris Agreement, which was adopted in December 2015, calls for keeping the average global temperature rise well below 2°C above pre-industrial levels. It also calls for efforts to limit this temperature increase even further to 1.5°C in consideration of countries that are particularly vulnerable to climate change. Reaching this target means that we limit global greenhouse gas emissions in the second half of this century to a level that allows for these emissions to be absorbed naturally by ecosystems. In other words, it means that we need to reduce the amount of greenhouse gas emissions by human activities to substantially zero.

Power generation systems that do not rely on fossil fuels are crucial to reducing greenhouse gas emissions in an effective manner. Accordingly, the introduction of renewable energy such as photovoltaics (PV) and wind power is expected to further expand going forward. At the same time, there will likely be a growing need for technologies that support renewable energy such as adjusted flexible operation. The ways of producing hydrogen and stably using it are being examined to meet requirements for fuel that does not emit CO_2 used for transportation or for industrial heat sources for which renewable energy is difficult to apply.

One way to produce hydrogen is through water electrolysis, which uses renewable energy as its power source. However, to supply hydrogen produced through water electrolysis in an economically viable manner, it is necessary to realize such accomplishments as the widespread application of renewable energy and innovation in water electrolysis technologies. This means that a considerable amount of time is needed before we can produce hydrogen efficiently using water electrolysis. To fill in the gap until such accomplishments are reached, it is imperative that we realize another carbon-free production method for hydrogen over the medium term. We believe this can be accomplished by combining the production of hydrogen using reformed fossil fuels such as natural gas with the application of the carbon capture utilization and storage (CCUS) process, which recovers the large amount of CO_2 that is generated when producing hydrogen in this way and either reuses it or stores it in the ground so that it will not enter the atmosphere.

MHI Group possesses a wide range of products and technologies related to a CO_2-free hydrogen supply chain. Among these, this section introduces our hydrogen combustion gas turbines, ammonia plants, and CO_2 capture devices.

Outlook for Hydrogen Ratio by Source over the Medium to Long Term



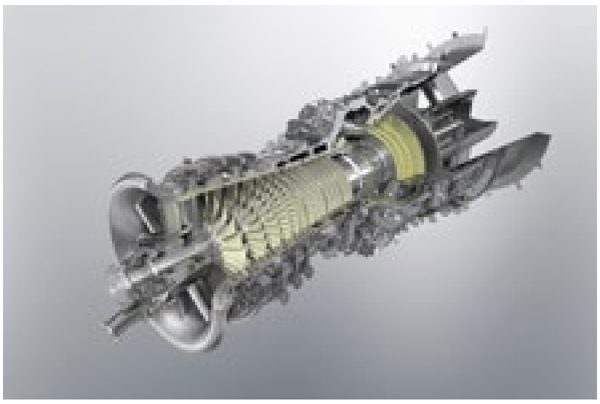
Source: Prepared by Mitsubishi Hitachi Power Systems, Ltd.

Power Generation Systems That Use Hydrogen Fuel

Mitsubishi Hitachi Power Systems, Ltd. (MHPS) has invented hydrogen-fired gas turbine systems that only require the conversion of burners in gas turbines at existing power plants in order to be used. Accordingly, this system is expected to help reduce the cost-related hurdles to convert to hydrogen fuel, which in turn will promote the smooth transition to a hydrogen society. With support from the New Energy and Industrial Technology Development Organization (NEDO), MHPS is pursuing the development of hydrogen-mixed combustion burners that mix hydrogen with natural gas used as fuel as well as hydrogen-specialized combustion burners that generate power using only hydrogen. As hydrogen burns at a faster rate than natural gas, there is a greater risk of backfire occurring compared with burning natural gas on its own. Accordingly, for burners used in hydrogen gas turbines, there is a need to work toward reducing NOx emissions and stabilizing the combustion process itself, centered on making improvements to avoid backfire. There is also a need to enhance the marketability in terms of such factors as lower costs and longer life in conjunction with pursuing their development and practical application.

In 2018, MHPS successfully developed a burner that is able to use natural gas with a hydrogen mixture of 30%. Test combustion using these newly developed hydrogen-mixed combustion burners showed that NOx emissions caused by hydrogen combustion can be kept at conventional levels, and that the operation can be carried out without the occurrence of backfire or a remarkable increase in combustion pressure fluctuations. Serving as a technology that can respond to outputs equivalent to 700 MW (gas turbine combined cycle [GTCC] system inlet temperature of 1,600°C), these hydrogen-mixed combustion burners can deliver an approximately 10% reduction in CO_2 emissions when generating power, compared with conventional natural gas-fired GTCC systems.

In addition, MHPS began participation in a hydrogen conversion project for the Magnum Power Plant (GTCC with a total output of 1.32GW) in the Netherlands, which is operated by Swedish power company Vattenfall AB. This project aims to convert one of the three power generation facilities at the Magnum Power Plant, which centers on the M701F gas turbine supplied by MHPS, to 100% hydrogen-specialized combustion by 2025, thereby confirming the feasibility of converting to hydrogen combustion. With natural gas-fired systems, one 440 MW GTCC can emit up to 1.30 million tons of CO_2 per year, and converting such a facility to hydrogen fuel will significantly reduce this emission, almost eliminating it altogether.



Hydrogen combustion gas turbine

Introduction
Strategy
Business
Governance
Data

Realizing the Stable Use of Hydrogen

To enable the stable and large volume use of hydrogen needed to serve as fuel for power generation systems and other purposes, it is necessary to build a supply chain that covers all steps from hydrogen production to hydrogen transport and storage.

Comprehensive hydrogen usage plans are shown globally that take into account the perspective of hydrogen transport, storage, and use from the stage of production. These include systems that utilize the carbon capture and storage (CCS) method to process the CO_2 that is emitted during the production of fossil fuel derived hydrogen. Particularly in Europe, a region that benefits from well-developed pipelines of natural gas, hydrogen gas utilization is being promoted as a kind of comprehensive infrastructure that transcends national borders.

Meanwhile, hydrogen must be liquefied in order to transport it in large volumes over long distances or across oceans. In light of this, R&D activities are being advanced on three kinds of hydrogen transport media (energy carriers): liquefied hydrogen, organic hydride, and ammonia (NH_3). Among these three, we concluded that ammonia possesses the merits listed below and is expected to play an important role as a CO_2-free fuel. The transport of hydrogen using ammonia is also an area in which MHI Group's technologies can make a significant contribution.

1. If pressurized at room temperature, ammonia becomes a liquid in the same manner as liquefied petroleum gas (LPG). This means that ammonia can be handled as easily as LPG and that existing infrastructure can be utilized.
2. Ammonia is already being internationally distributed in high volumes as an intermediate substance for fertilizer and other chemicals.
3. Ammonia itself can be used as fuel without having to convert it back to hydrogen.

On the other hand, ammonia is toxic and emits an odor when it leaks, making the use of ammonia nearby ordinary households an issue. In consideration of this issue, ammonia will likely be used primarily in locations where it can be managed thoroughly, such as at power plants and factories and on cargo vessels.

For micro gas turbines and other small gas turbines, research is being conducted on power generation methods involving the direct burning of ammonia.

In addition, for large gas turbines, MHPS is examining power generation systems that burn hydrogen that has been efficiently converted from ammonia using the waste heat of gas turbines.

The Haber–Bosch process, made practical by German chemists Fritz Haber and Carl Bosch in 1913, has been the main industrial procedure for the production of ammonia. This process involves synthesizing ammonia from hydrogen and nitrogen using an iron-based catalyst. Since 1958, Mitsubishi Heavy Industries Engineering, Ltd. (MHIENG) has been supplying a large number of ammonia plants to various countries around the world. In current ammonia synthesis, natural gas is generally used as a feed stock.

Ammonia plant

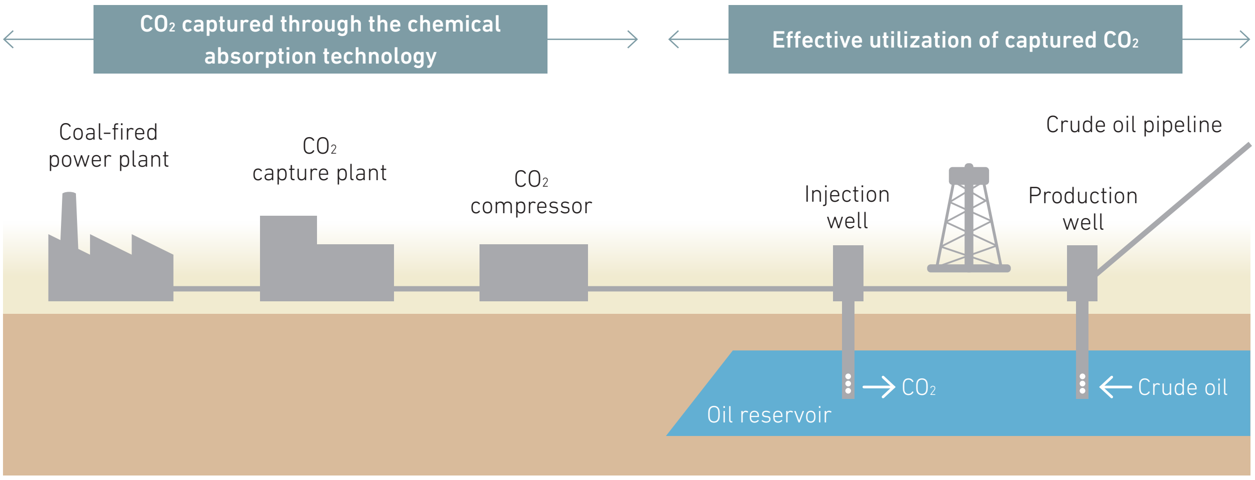
Capturing CO_2

To successfully build a CO_2-free supply chain for hydrogen fuel mentioned above, CO_2 capture plant for the implementation of CCUS are essential. MHIENG boasts the world's best track record in the field of commercial CO_2 capture plants, possessing technologies that can capture over 90% of the CO_2 emitted from combustion exhaust gas (KM CDR Process® developed in cooperation with The Kansai Electric Power Co., Inc.).

In January 2017, MHIENG supplied the world's largest CO_2 capture plant to a coal-fired power plant in the U.S. state of Texas. The CO_2 captured from this plant is used for enhanced oil recovery (EOR) in Texas's West Ranch Oilfield, which is an aging oil field. By injecting CO_2 into this oil field, the recovery rate of crude oil is being enhanced.

CO_2 capture plant

KM CDR Process® is a registered trademark of Mitsubishi Heavy Industries Engineering, Ltd., in Japan, the United States of America, European Union (EUTM), Norway, Australia, and China.



In addition to the initiatives introduced in this section, MHI Group is promoting the development of technologies related to hydrogen supply chains in a broad range of fields. Going forward, the Group will contribute to the establishment of hydrogen supply chains as an effort to combat climate change.