Kawasaki Heavy Industries
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Scope

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Contents

About the Cover
An operational inspection being conducted on the hydrogen gas turbine at the Hydrogen CGS Energy Center. See *Special Feature* for details.

A co-generation plant on Kobe's Port Island with a power generator driven by a hydrogen gas turbine and a boiler. The plant has successfully supplied energy generated using 100% hydrogen to urban areas.

The "Hydrogen Road" Has Arrived at the Demonstration Stage: A Step Forward in Realizing a Hydrogen-Based Society

In the Spring 2015 issue of SCOPE, we carried a feature story, "The Hydrogen Road: Paving the Way to a Hydrogen Fueled Future," in which we introduced Kawasaki's four-phase process (production, transportation, storage, and utilization) in establishing a hydrogen supply chain. Three years have passed since then, and all areas involved in the supply chain have seen technological advancements. Concurrently, a vision to realize the commercialization of hydrogen-based energy is gaining momentum at both the domestic and international levels.

Global Endeavors Begin for Promoting the Utilization of Hydrogen

It is now a fact that world leaders have begun the transition to a hydrogen economy. In January 2017, the Hydrogen Council was formed as a global initiative by 13 leading energy, transport, and industry companies with a united vision and long-term ambition to foster the hydrogen energy transition.

The Council is currently composed of Kawasaki, Toyota, Honda, Iwatani, and other Japanese companies, as well as Air Liquide (France), Alstom (France), Anglo American (U.K.), BMW Group (Germany), Royal Dutch Shell (U.K., the Netherlands), and other multinationals.

In November of the same year, the Council published a first-of-its-kind study on a globally quantified vision of the role of hydrogen. The report states that hydrogen could account for almost one-fifth of the total final energy consumed by 2050, which would reduce annual CO_2 emissions by roughly six gigatons when compared to today's technologies. It also says that this volume of reduction contributes roughly 20% of the additional abatement required to limit global

At the heart of the co-generation system on Kobe's Port Island (photo on page 4) is this hydrogen gas turbine, which drives the power generator, and using waste heat, operates the boiler.

The hydrogen co-generation plant (located in the central part of the photo) on Kobe's Port Island.

warming to two degrees Celsius. According to its projection, a market for hydrogen and hydrogen technologies with revenues of more than US$2.5 trillion per year and jobs for more than 30 million people globally can be achieved. In March 2018, 11 companies including 3M (U.S.) and Bosch (Germany) decided to join the Council.

Moreover, we are seeing a global trend where governments around the world are focusing more on the use of hydrogen energy: the U.S. and EU have formulated their own hydrogen strategies, and China, the largest producer of CO_2, has set national strategies on developing automobiles with a focus on hydrogen energy.

Turning our eyes to Japan, the government formulated "The Basic Hydrogen Strategy" in December 2017, which positioned hydrogen as the energy of the future that is as effective as renewable energy resources, and set forth targets to be achieved.

These targets include: 1. Increase the number of fuel cell vehicles (automobiles and buses) and hydrogen stations; 2. Aim to procure around 10 million tons of hydrogen fuel per year (equivalent to 30 GW in power generation capacity); and 3. Actively promote the use of inexpensive resources such as brown coal and renewable energies from outside the country, and for that purpose, develop an international hydrogen supply chain.

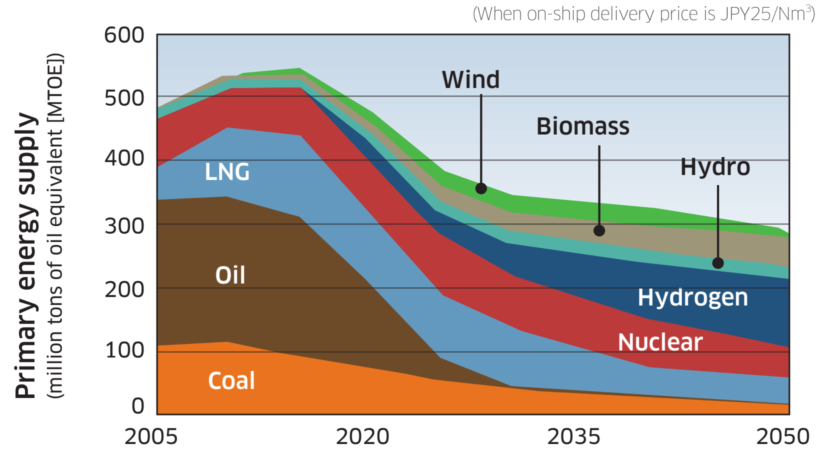
HySTRA Spearheads Technological Advancements

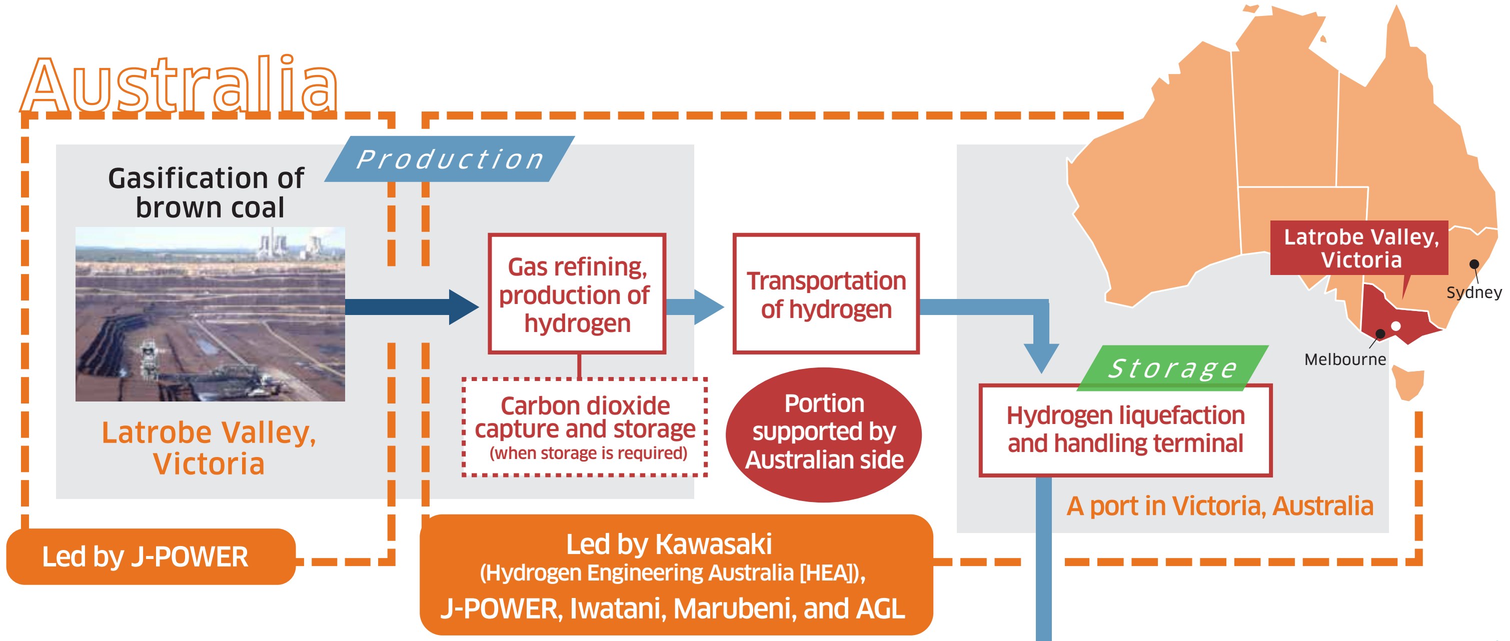
Even before "The Basic Hydrogen Strategy" was established, development efforts for hydrogen-related technologies were underway. In February 2016, the CO_2-free Hydrogen Energy Supply-Chain Technology Research Association (HySTRA) was formed by a consortium of four companies, with the objective of launching a commercial-use hydrogen supply chain around 2030 to serve as a platform for producing, transporting, storing, and using hydrogen. The mission of this consortium, comprising Kawasaki, Iwatani, Shell Japan, and Electric Power Development (J-POWER), is to implement a pilot project subsidized by the New Energy and Industrial Technology Development Organization (NEDO) for building a hydrogen supply chain.

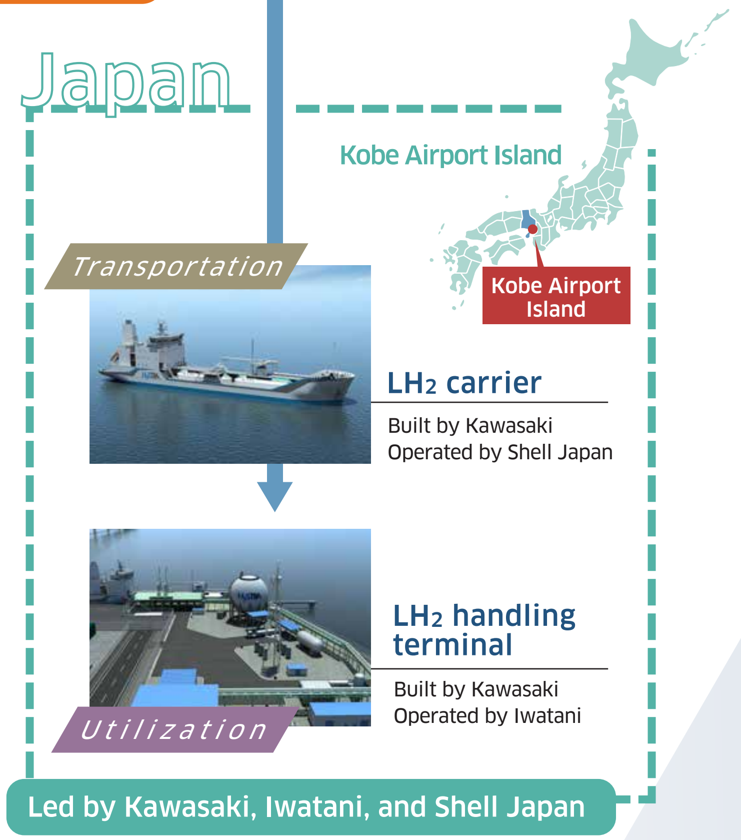
Projection of Energy Demand Based on Simulation

(Trial calculation by the Institute of Applied Energy)

(When on-ship delivery price is JPY25/Nm³)







Launch of the Hydrogen Council Spearheaded by Global Corporations

Photo courtesy of Hydrogen Council

In January 2017, the Hydrogen Council was formed as a global initiative by 13 leading energy, transport, and industry companies with a united vision and long-term ambition to foster the hydrogen energy transition. It is a first-of-its-kind initiative led by a group of global business CEOs to drive forward the realization of a vision for the role of hydrogen. It is currently (2018) comprised of 39 companies (steering members and supporting members), including: 3M, Air Liquide, Alstom, Anglo American, Audi, BMW Group, China Energy, Daimler, General Motors, Honda, Hyundai Motor, Iwatani, JXTG Nippon Oil & Energy, Kawasaki, Royal Dutch Shell, The Bosch Group, The Linde Group, Total, and Toyota.

Each member of HySTRA assumed responsibilities as follows: 1. J-POWER would be developing a hydrogen production technology utilizing brown coal mined in Victoria, Australia; 2. Kawasaki and Shell Japan would build a liquefied hydrogen (LH_2) carrier and establish a technology that enables transportation of LH_2; and 3. Kawasaki and Iwatani would build LH_2 handling terminals and establish technologies for operating them.

The Australian portion (led by the Federal Government of Australia and the State Government of Victoria) of NEDO's pilot project would include supporting the construction of production and liquefaction facilities for hydrogen and its handling terminals.

Kawasaki serves as a secretariat for HySTRA and is tasked not only with leading the technological development projects, but also with the coordination with the Australian government. Kawasaki's long-time efforts that began in the early 1970s in developing cryogenic and hydrogen technologies are reaching a new stage, with a focus on contribution to society.

Production

Right: A scene from the launch ceremony of the pilot project in April 2018, organized by the Australian Government and the Victoria State Government. Local communities welcomed the launch, with a view that Australia will be contributing to the conservation of the global environment through this first-of-its-kind system. Left: A vast brown coal mine in the Latrobe Valley, located in the south-west part of Australia.

Collaborative Hydrogen Production Project with the Australian Government

Economical and Environmental Benefits of Utilizing Brown Coal (Unused Resource) Being Recognized

The Latrobe Valley, located 150 km east of Melbourne, Australia, has brown coal seams that stretch 14 km, and the total amount of energy stored there is estimated to be equivalent to 240 years of gross power generation in Japan.

In this area, J-POWER is leading the gasification of brown coal as part of a NEDO pilot project ("NEDO portion"). Separate from the NEDO portion, the construction of a pilot plant subsidized by the Australian Government and the Victoria State Government is about to begin ("Australian portion"). The plant is composed of facilities required for processing after the production of hydrogen gas, such as hydrogen gas refining, production of liquefied hydrogen (LH_2), its storage, and handling (loading/unloading).

The Australian portion is led by a consortium of five companies, namely Kawasaki, Iwatani, J-POWER, Marubeni, and AGL, a leading energy firm in Australia. Hydrogen Engineering Australia Pty Ltd. (HEA), Kawasaki's subsidiary, is the main contractor for this project with the Australian Government.

The project manager, Yasushi Yoshino, General Manager of the HEA Melbourne Office, comments, "Technological challenges for the Australian portion have already been resolved, and we are now focusing on gaining the understanding of the local communities with regard to how commercialization of hydrogen energy can contribute to Australia, economically and environmentally."

Local response to the pilot project is favorable, and the State of Victoria is welcoming it, saying that this first-of-its-kind project can lead the way to a hydrogen-based society, and that a few hundred jobs are expected to be created as a result. Meanwhile, because the environmental awareness of the Australian population is very high, people are paying close attention to the environmental effects of utilizing brown coal, a fossil fuel, and how CO_2 generated during the production phase of hydrogen will be treated.

Brown coal (lignite) is a geologically young coal with a high moisture content (50 to 60%) and when it dries, it can catch fire naturally. This makes it difficult to export and it has thus been used solely for local power generation. However, Yoshino says, "Utilization of brown coal as a raw material for hydrogen energy offsets these shortcomings. A value judgment that this project can create economic added-value from this unused resource (i.e., brown coal) is being established."

With regard to CO_2 generated during hydrogen production using brown coal, the HEA is coordinating with the CarbonNet Project led by the Australian Government, which is investigating the potential for establishing a commercial-scale carbon capture and storage (CCS) network.

For the Australian portion, Kawasaki will be building the handling terminal and evaluating its operation. The basic design of the terminal has been completed, and construction is scheduled to commence in April 2019, after the selection of material suppliers and construction contractors. The terminal is slated to be completed in June 2020, followed by a test run.

By fall 2020, the production of LH_2 will commence and the terminal will be ready for loading it onto an LH_2 carrier for transportation.

Yasushi Yoshino
General Manager, Melbourne Office
Hydrogen Engineering Australia Pty Ltd. (HEA)

An artist's rendition of a system to produce hydrogen from brown coal in the Latrobe Valley. The system is being constructed under the leadership of J-POWER. The hydrogen produced through this system will then undergo refining, loading, and other downstream processes which are carried out as part of the Australian portion.

Storage
Transportation

Construction of a Liquefied Hydrogen (LH_2) Carrier and Handling Terminal

Pioneering a New Era of Energy Use by Achieving the World's First Long-Distance Transportation of Hydrogen

When the temperature of hydrogen is lowered to -253°C, it liquefies, and the volume reduces to approximately one eight-hundredth that of the gaseous state, making mass transport far more efficient. An LH_2 carrier is tasked with marine transport of LH_2 from Australia to Japan, a journey of about 9,000 km.

As a member of HySTRA, Kawasaki is responsible for construction of the LH_2 carrier, and Shell Japan is to operate the vessel. The construction of the pilot vessel is scheduled to begin in the second half of fiscal 2018, and it will set out on its maiden voyage from Japan to Australia at the end of fiscal 2020.

An LH_2 tank with a capacity of 1,250 m^3 will be installed on the vessel. The tank is designed with a double-hulled, thermos-like structure and its design pressure is on the order of five times standard atmospheric pressure.

Kenjiro Shindo, Deputy Senior Manager of the Hydrogen Project Development Center under the Corporate Technology Division, comments, "The LH_2 tanks are required to have thermal insulation performance ten times greater than that for liquefied natural gas (LNG), and Kawasaki is utilizing expertise gained from manufacturing LNG transport tanks and LH_2 tanks at the Tanegashima Space Center."

He adds, "Because it will be installed on the world's first LH_2 carrier, we are making sure its safety performance is high, and we have been incorporating safety assessments associated with emergency hydrogen release as part of the development of transport tank-related technologies. LH_2 is more evaporable than LNG, and because its molecules are smaller, it leaks more easily. To accommodate such characteristics, we are leveraging manufacturing expertise gained through LNG tank production, and from many other technologies developed for products used everywhere from underground to outer space."

For the handling terminal that will be receiving LH_2 from Australia, Kawasaki will be building a plant system on the Kobe Airport Island to be operated by Iwatani. As with the tanks on the carrier, insulation and sealing performance of the facilities for unloading LH_2 from the carrier into storage tanks are key to ensuring safety.

"We developed a technique using double-walled flexible hoses with high insulation and sealing performance as compared to conventional handling systems used for LNG, in order to secure the connection between the swaying LH_2 carrier and the onshore storage tank. This will be the world's first pilot test of this innovative approach," says Shindo.

Because mass marine transport of LH_2 has never been carried out, a set of new regulations had to be formulated by the International Maritime Organization (IMO) to ensure its safe transport. After many deliberations based on proposals from Japan, in 2016, the IMO officially approved the safety requirements as proposed by Japan.

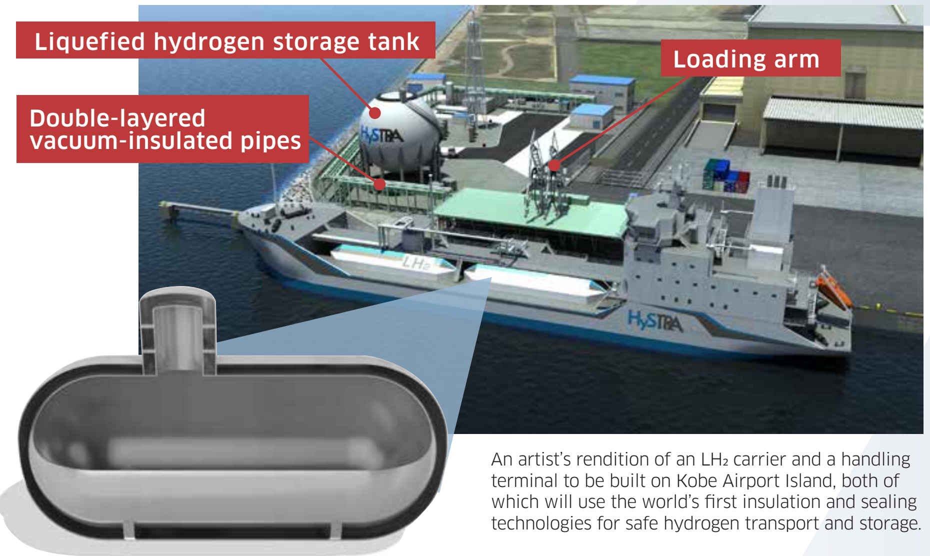
This means that the building of the world's first LH_2 carrier will make not only a technological contribution to the industry, but also serve as a way to validate the international standards for safe LH_2 transport, and lead to further establishment of such standards.

"Because the actual carrier is not yet completed, the IMO requirements are interim recommendations. If the pilot vessel is approved as the world's first LH_2 carrier, and if we gain experience operating it, the knowledge will be channeled into establishment of international rules," Shindo comments.

The manufacturers and users partnering under HySTRA aspire to achieve commercialized LH_2 transport through safe and solid verification of this first-of-its-kind technology.

Kenjiro Shindo
Deputy Manager, Project Promotion Department
Manager, Hydrogen Energy Chain Promotion Section 1
Hydrogen Project Development Center
Corporate Technology Division
Kawasaki Heavy Industries, Ltd.

In 2016, IMO officially approved the safety standard requirements proposed by Japan for LH_2 transport, which is the first rung on the ladder for contributing to the establishment of international rules.



An artist's rendition of an LH_2 carrier and a handling terminal to be built on Kobe Airport Island, both of which will use the world's first insulation and sealing technologies for safe hydrogen transport and storage.

Co-generation Utilizing a Hydrogen Gas Turbine

Capacity and Safety of Large-scale Power Generation in Urban Areas Verified

On April 19 and 20, 2018, the world's first verification test was successfully completed for providing both heat and power to urban areas on Kobe's Port Island, using a gas turbine fueled by 100% hydrogen.

During the test, heat (steam and hot water) and power were successfully provided to four facilities, including a sports center and a municipal hospital in the vicinity, from the co-generation system (CGS) comprising a power generator and a boiler built on the campus of the former Minatojima Clean Center (waste treatment facility) in Kobe City. At the sports center, hot water was used for its swimming pool, hot-water supply, and heating, while at the municipal hospital, steam was used for heating water, room heating, and sterilization of medical equipment and utensils. The energy supplied amounted to 1,100 kW of electricity and 2,800 kW of heat.

Named "The Smart Community Technology Development Project Utilizing Hydrogen Cogeneration Systems," this project to generate heat and power utilizing a hydrogen-fueled gas turbine was implemented as part of NEDO's "Technology Development for the Realization of a Hydrogen Society" program. It aims at achieving development and verification of an integrated energy management system (EMS) that enables optimal and efficient use of power, heat, and hydrogen by users in the community.

In this project, for which a series of similar tests is planned, Kawasaki is responsible for providing a gas turbine, a power generator, and a boiler, and Obayashi Corporation is currently developing the integrated EMS.

Mitsugu Ashikaga, Deputy Senior Manager of the Project Control Department for the Hydrogen Project Development Center under Kawasaki's Corporate Technology Division, comments, "The mission of the test was to collect data associated with gas turbine performance, which changes seasonally due to variable demand, and to establish control techniques for the integrated EMS. The collected data and its analyses are essential in gaining sophisticated and practical expertise."

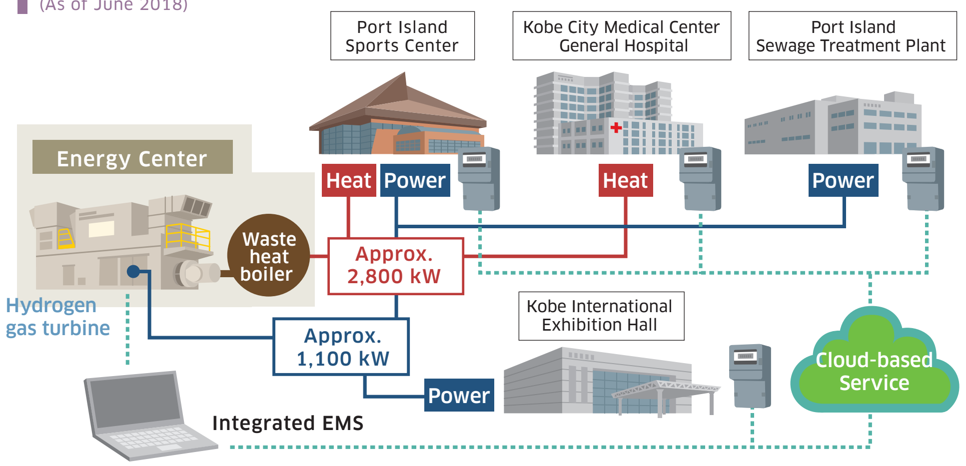
Kawasaki has been developing the gas turbine used for the project. It allows usage of either hydrogen or natural gas alone, as well as flexible adjustment of any hydrogen/natural gas combustion ratio.

When only hydrogen is used, the temperature of the flame is high and the flame is easily spread, which results in burner damage and emissions of nitrogen oxide (NO_x). Kawasaki resolved these problems by developing a fuel injection valve with a novel shape and adopting a method through which water and fuel are injected together.

Ashikaga says, "The most significant achievement of the verification test was that we were able to verify that hydrogen energy could be used safely in a community setting." Robust design and building methods are applied not only to the gas turbine but also to the entire plant, assuring that at both the plant capacity and the operational safety levels, practical power generation for large-scale facilities using hydrogen is possible.

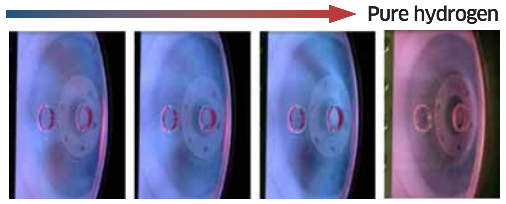
Conceptual Diagram of the Hydrogen Power Generation Demonstration System in Kobe

(As of June 2018)



Mitsugu Ashikaga
Deputy Senior Manager,
Project Control Department
Hydrogen Project Development Center
Corporate Technology Division
Kawasaki Heavy Industries, Ltd.

Flame Behavior (measurement visualization)



This gas turbine not only allows combustion solely of hydrogen or natural gas, but also a variable hydrogen/natural gas combustion ratio. The photos above show how flame behavior changes according to the ratio of hydrogen/natural gas in the fuel mixture. Because the hydrogen flame temperature is high and the flame is easily spread, it could result in equipment damage. To resolve this without redesigning the gas turbine body, a new type of burner for hydrogen was developed (the cylindrical section in the illustration).

From the Project Team

Fostering a "Hydrogen-Oriented Culture" Without Over-emphasis on Technological Advancement

When Kawasaki commenced its research on hydrogen energy in 2009, driven by its conviction that hydrogen possesses great potential in becoming the pillar of transition to clean energy, there were only a handful of people who made similar forecasts. In fact, this continued until just a few years ago. Now, the world views hydrogen as a promising driver of energy transition, and the world's governments, prominent corporations, and NPOs are moving toward more fully incorporating hydrogen into their policy-making/business strategies, which clearly reflects the momentum that hydrogen is gaining globally.

The field of hydrogen-related technologies is often described as "multi-player realm," in which there is no predominant corporation taking leadership, but a variety of stakeholders and businesses contribute collaboratively to develop technologies and applications, leveraging their capabilities based on their interests. Kawasaki, a company that has been spearheading this pro-hydrogen energy movement, has maintained an unrivaled belief in the bright future of hydrogen, and we confidently view ourselves as a fitting navigator for this endeavor.

Motohiko Nishimura
Associate Officer, Deputy General Manager,
Hydrogen Project Development Center
Corporate Technology Division
Kawasaki Heavy Industries, Ltd.

With the global interest in hydrogen heightening, we are seeing some technological projects already arriving at near-completion and undergoing verification tests. Something that was conceived as a simple concept is now manifesting itself in a concrete form. As a member of the "hydrogen club," I personally am very excited about these developments, and am always thinking about how wonderful it would be if many more initiatives could be launched.

The downside of this multi-player collaboration in developing and bringing the technologies to the verification stage, however, is that it entails fierce industry competition, necessitates the securing of technological safety at a sophisticated level, and calls for ingenious coordination among the players. We must therefore avoid over-emphasis on technological advancement, but instead work in partnership with society to build a consensus on how hydrogen energy should be commercialized, and how a "Hydrogen-Oriented Culture" can be fostered.

In that regard, global think tank research on the potential of hydrogen energy and the development of environmental performance indicators should bring about diversification, deepening, and spreading of hydrogen initiatives. Moreover, hydrogen production in Australia, verification tests at Kobe's Port Island involving a co-generation system driven by a hydrogen gas turbine, and other initiatives, should teach us not only how environmental issues can be resolved, but also how the relationship among humans, energies, and technologies can be established so comprehensively that it contributes to creating jobs, activating rural areas, and making people's lives more comfortable.

Kawasaki is aiming at establishing a hydrogen energy supply chain in cooperation with the participating HySTRA companies, with a goal of conducting pilot tests in 2020. Another goal we have is to achieve commercial use of the supply chain by 2030. To that end, we are committing ourselves to fostering a "Hydrogen-Oriented Culture" and to maturing it further.

Looking Forward to Tomorrow

The Hydrogen 2030 Vision, Formulated by the Hydrogen Council, Based on a First-of-Its-Kind Study

The Hydrogen Council, a global initiative for promoting hydrogen energy, released a report containing the first-ever globally quantified vision of the role of hydrogen, developed with support from McKinsey & Company. The roadmap for introducing hydrogen energy is outlined in the graph on the right. According to the report, hydrogen energy use should begin by 2030 in the power generation and transportation sectors, as well as for heating and powering buildings. By 2050, the hydrogen market is expected to increase ten-fold as compared with today, with applications extending to industrial heat use and feedstock.