Energy Carriers
Becoming a New Energy Society

Leading the World in Hydrogen Energy Utilization; Creating a Low-Carbon, Hydrogen-Based Society

Reducing CO₂ emissions is a global issue. But for Japan, a country poor in energy resources, developing renewable energy and new eco-friendly sources of energy comparable to nuclear power is a critical factor to maintain our place as a leader in the international community. Hydrogen—which produces only safe, clean water after combustion—looks to be the best candidate for large-scale utilization as a new source of energy. Technology advancements have begun to offer answers to the issues of hydrogen production, transport, storage costs, and safety. Now, we are beginning to see concrete results to the initiatives that will put Japan on the forefront as a low-carbon, hydrogen-based society.

Program Director
Shigeru Muraki
Tokyo Gas Co., Ltd.
Executive Advisor

Profile
Shigeru Muraki joined Tokyo Gas Co., Ltd. in 1972. In 2000, he was named general manager of the Gas Resources department, and in 2002, he was named executive officer and general manager of the Gas Resources department. Mr. Muraki was subsequently promoted to senior executive officer and chief executive of the Tokyo Gas R&D Division in 2004, and then senior executive officer, chief executive of energy solution division in 2007. In 2010, he was named executive vice president and chief executive of the Energy Solution Division. In 2014, Mr. Muraki was elected vice chairman of Tokyo Gas, and in 2015 he was named Executive Advisor.

Research and Development Topics

1. Develop energy carriers and identify promising candidates
Advance the utilization of liquid hydrogen, organic hydrides, and ammonia as energy carriers for hydrogen production, transport, and storage; structure a practical cost model to serve as a foundation for a hydrogen energy value chain.

2. Develop peripheral technologies supporting a low-cost, highly efficient hydrogen value chain
Develop highly efficient hydrogen production technologies using renewable energy. Develop technologies for organic hydride and ammonia production, as well as hydrogen separation. Develop and demonstrate highly efficient technologies for fuel cells, turbines, and engines using hydrogen and energy carriers.

3. Conduct research and development linked to safety standards, deregulation for hydrogen transportation and use
Perform risk assessments for energy carriers, including spill accident simulation analysis, atmospheric diffusion modeling, etc. to collect basic data for approvals and licensing, safety policies, and risk communication. Set safety policies for energy carriers; publicly disclose carrier assessment results and reflect these results in ongoing development work.

*Energy Carriers R&D Conceptual Overview*
Revolutionary progress in ammonia power generation

Ammonia is a hydrogen carrier successfully used in the generation of electricity. This success shows the potential of ammonia in practical use.

- Successful power generation using fuel cells directly fueled by ammonia
  Successful power generation from the world’s largest (200W-class) Solid Oxide Fuel Cell (SOFC), fueled directly by ammonia. This is the beginning of systematization for practical use in small-scale power generation.

- The world’s first successful ammonia single fuel combustion/mixed-fuel combustion power generation in a 50KW-class gas turbine
  This program was the first in the world to successfully generate power in a 50KW-class gas turbine using methane-ammonia mixed fuel combustion (41.8kW) and ammonia single-fuel combustion (41.8kW). This has led to the identification of processing conditions for NOx using denitrification equipment. Ammonia has proven its potential for use in thermal power generation.

As a program director (PD), Shigeru Muraki is responsible for establishing and promoting research and development plans. The Promoting Committee is chaired by Mr. Muraki with the Cabinet Office serving as secretariat. The Committee is composed of relevant ministries, agencies, and experts who provide overall coordination. The Japan Science and Technology Agency (JST) exercises its authority as the management agency. Coordinating with other ministries, the program develops scenarios for the adoption of hydrogen to produce optimized research and development topics.

Exit Strategies

- Promote wider adoption through technology assessment and standards (2017 - )
  Develop and test hydrogen carrier technologies. Evaluate tests based on economies, safety, and other factors to create safety standards for international acceptance, establishing a basis for worldwide hydrogen carrier use. Use the results of this work to study scenario for utilizing hydrogen energy engaging in technological development driven by strategic investment allocation.

- Prove research and development results in real-world applications (2018 - )
  Demonstrate project successes in hydrogen stations, fuel cells, turbines and other technologies using energy carriers in locations where the 2020 Tokyo Olympics/Paralympics games are held. Introduce technologies for producing, transporting, storing, and using hydrogen; test hydrogen and energy carriers in practical electricity/heat production, vehicles, etc. in selected locations.

- Promote international collaboration for using renewable energy overseas (2018 - )
  Promote international collaborative development of CO2-free hydrogen and energy carrier production in overseas markets. Demonstrate ranging from hydrogen energy production to usage.
Hydrogen is expected to play an important role as a source of energy that both fights global warming and improves energy security. Research and development under this program employs a view that spans the entire value chain, including hydrogen production, storage, transport, and use. At present, we are moving from elemental technology development to the system design stage. At the same time, we are speeding efforts toward proof-of-concept demonstration tests.

Visions of Practical Utilization with the World’s First Successful Test of Ammonia-Based Direct Power Generation Technology

Mr. Shigeru Muraki, the director of this program, says, “We are seeing a number of specific successes in this program. Of those, research into ammonia-based power generation has produced results ahead of schedule.” This program is ahead of those in other countries, having demonstrated power generation using methane-ammonia mixed-fuel combustion and ammonia single fuel combustion, both in a 50kW-class turbine. Taking these results, program engineers have started working on a demonstration test for a 2MW-class gas turbine. Studies have also been initiated for practical large-scale power generation with the cooperation of major national power companies.

Our ammonia fuel cell research resulted in successful power generation for a 200W-class SOFC stack, one of the largest in the world. Prototyping and design are currently underway for a 1kW-class power generation system. Mr. Muraki says, “Ammonia is distributed in great amounts throughout the world, and the cost of importing ammonia to Japan is clear. Advancing technology for use in gas turbines and fuel cells could gradually lead to CO₂-free ammonia production.”

The program has also made advancements in developing high-temperature solar thermal systems that could lead to CO₂-free hydrogen and ammonia production. Now, program engineers are working on plans for practical demonstration tests, having narrowed research to light and heat collection systems and heating media.

Mr. Muraki points out that the aim of the program is to achieve heat collection of 650°C. Accordingly, the most desirable locations for demonstration tests are sunbelt regions where the concentration of sunlight is highest. Says Muraki, “We have already started sharing information with companies overseas.” The program continues to pursue the possibilities of creating a CO₂-free hydrogen value chain, even after the completion of the SIP program.

Steady Progress in Fuel Cell Vehicle Technological Development and Safety Assessment Research

Another important field of use for energy carriers is that of supplying hydrogen to Fuel Cell Vehicles (FCV). This project focuses on organic hydride and ammonia. However, dehydrogenation and high purity hydrogen purification technologies lie at the center of both.

Methylcyclohexane and hydrogenated toluene are used for organic hydride. After operational evaluations of 10Nm³/h dehydrogenation pilot systems, work has started to design 300Nm³/h dehydrogenation systems, which is a standard size for Japan’s hydrogen stations.

The program is also developing practical carbon membrane modules as a low-cost hydrogen purification technique. At present, research has been completed for the elemental technologies required for ammonia-based
dehydrogenation and purification. Now, work is progressing toward the design of 10Nm³/h dehydrogenation pilot systems. In parallel, program engineers are conducting safety assessment research, while discussions related to hydrogen station facility performance requirements and social risks are bearing fruit. Mr. Muraki says “We plan to be able to provide data between 2017 and 2018 that will contribute to studies on deregulation.”

**Advancements in Hydrogen Utilization**

Significant progress has been made in technology utilizing hydrogen. In hydrogen gas turbine power generation, the program has successfully developed a gas turbine combustor capable of low NOx combustion using 100% hydrogen, without using water or steam usually necessary for such a process. Based on these successes, the New Energy and Industrial Technology Development Organization (NEDO) began the development of hydrogen single-fuel combustion turbines in fiscal 2016.

NEDO is producing conceptual designs for systems necessary for the loading and unloading of liquefied hydrogen. At the same time, coordination is ongoing with related agencies for safe loading/unloading measures and procedures.

**Focus on Results Toward Industry-Academia-Government Collaboration Beyond SIP**

Mr. Muraki says, “We won’t see the completion of a single development project during this program. What we want to do is create an optimal scheme, while being flexible in reviewing our research content.”

As for the future of this research, he says, “A hydrogen-based society is a long-term challenge. We must build an even stronger framework for industry-academia-government collaboration with the help of NEDO and the Council for Science, Technology and Innovation, based on the currently effective implementation structure.” Even after the program finishes, close cooperation will be required for the long road ahead.

### Future Plans

The schedule for research and development in each project current runs through fiscal 2018.

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<td><strong>Japan will continue in its unified efforts, coordinating between ministries and industry/academia/government entities. We will also conduct technological development with an eye toward international cooperation.</strong></td>
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**Cross-ministerial Strategic Innovation Promotion Program (SIP)**

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