Energy Carriers

Becoming a New Energy Society

Leading the World in Hydrogen Energy Utilization; Creating a Low-carbon, Hydrogen-based Society

Reducing CO_2 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 Energy 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.
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. He was later named Executive Advisor in 2015 and Advisor in 2017.

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

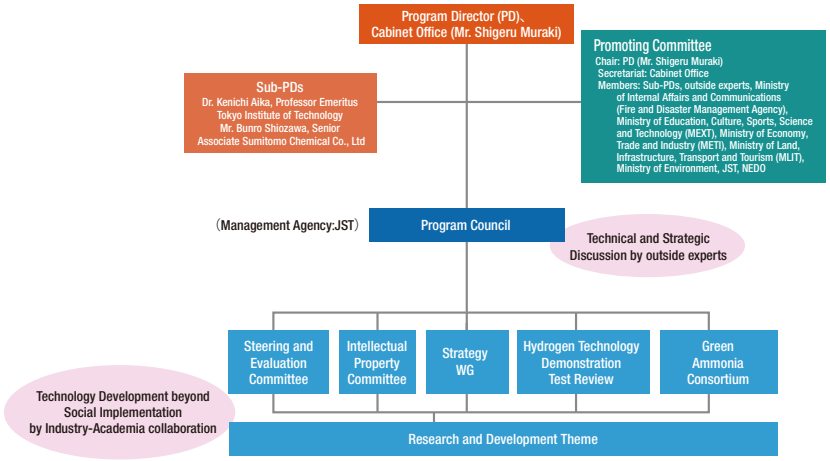
Develop highly efficient hydrogen production technologies using renewable energy. Develop technologies for organic hydride and ammonia production, as well as hydrogen separation. Develop and demonstrate highly efficient technologies for fuel cells, turbines, and engines using hydrogen and energy carriers.

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 and atmospheric diffusion modeling, to collect basic data for approvals and licensing, safety policies, and risk communication.

Implementation Structure

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.



Exit Strategies

Social Implementation of R&D's results

Implement the R&D's results related to technologies for producing, transporting and using hydrogen energy based on Ammonia in society from the 2020s.

International Collaboration

Promote international collaboration to construct the supply chain of ammonia produced by using CO_2-free hydrogen overseas.

Utilizing safety assessment research

Promote to utilize safety standards for loading system of liquid hydrogen and risk assessments related to hydrogen refueling station. Promote cooperation with ministries to rationalize rules utilizing results at this program.

Progress to Date

Great Evolution of Technologies related to Ammonia as Hydrogen Energy Carrier

This program showed lots of successful demonstration tests related to Ammonia as a hydrogen energy carrier. Relatively early utilization as CO_2-free fuel of Ammonia came to be expected. A road to the construction of ammonia value chain contributed to the low carbon society is getting clearer.

Mix combustion of Ammonia in coal fired boiler

- The world's first success in a trial to co-firing ammonia at the existing coal power plant. (ratio : 1MW-NH_3 feed / 120MW-Electricity).

- 20% co-firing test of ammonia with pulverized coal is succeeded using 10MW test furnace. NOx emission can be controlled at the same level as 100% coal firing condition.

Distributed power supply

- Power generation by 50kW class gas turbine is succeeded under the condition of co-fired 50% ammonia with city gas (methane) and 100% ammonia. Furthermore, power generation by 2MW commercial gas turbine is succeeded under the condition of co-fired 20% ammonia with city gas . Stable flame and NOx emission can be controlled.

- Test using 100% ammonia as a fuel is succeeded using 1kW hot module system. High efficiency and thermal independent operation are achieved.

Ammonia Production

- Started demonstration test of ammonia production at pilot plant adopting new catalysts developed for ammonia synthesis process using CO_2-free hydrogen derived from renewable energy.

Program Director **Shigeru Muraki** Interview

Experiments Have Proven the Possibilities for Hydrogen in Full-scale Adoption; System Design Moving Forward for Development as an Energy Carrier

Energy carrier research and development is ongoing toward the creation of a CO_2-free hydrogen society. Certain areas of elemental technology research have progressed sufficiently to support systems design. The world's first success in generating power directly from ammonia has been one of a series of accomplishments to date.

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.

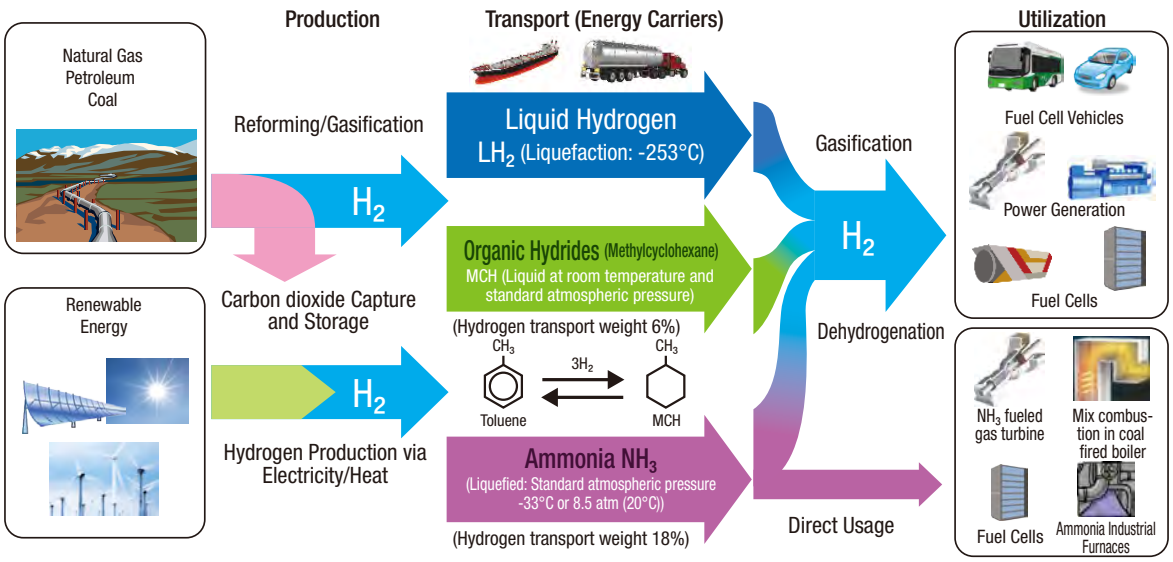
Visions of Practical Utilization with the World's First Successful Test of Ammonia-based Direct Power Generation Technology

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 larger results than the expectation." 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. Furthermore, the power generation in 2MW class one was achieved under co-fired 20% ammonia with natural gas. So, I was convinced that ammonia could be used as a fuel for power generation by small class gas turbine to large class one.

Following basic combustion tests using a pulverized coal burner for co-firing ammonia, We succeeded in power generation trial by the co-firing at a power company's existing coal power station after basic combustion tests using a pulverized coal burner. And also a boiler maker succeeded in 20% co-firing test with pulverized coal using 10MW furnace, the NOx emission could be controlled at the same level as 100% coal firing. We could show technologies of decreasing CO_2 emission without increasing NOx and large improvements of furnace. So, Power companies started the basic design for introducing them to coal power station.

Our research on ammonia fuel cell resulted in successful power generation for a 1kW-class SOFC stack and also the SOFC system self-supported using exhaust heat of SOFC. As the next step we are developing large-sized and high efficient systems for commercial and industrial applications. In addition, we are developing technologies on the utilization of ammonia as a substitute fuel for natural gas and heavy oil for industrial furnaces and marine engine. Mr. Muraki says, "Ammonia is distributed in great amounts throughout the world, and the cost of importing ammonia to Japan is clear. Advancing technology

•Hydrogen Production, Transportation and Usage



for use in gas turbines and fuel cells could gradually lead to CO_2-free ammonia production."

The program has started demonstration test of ammonia production from CO_2-free hydrogen derived from renewable energy.

The program continues to pursue the possibilities of creating a CO_2-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 hydrides 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 10Nm^3/h dehydrogenation pilot systems, work has finished to design 300Nm^3/h dehydrogenation systems, which is a standard size for Japan's hydrogen stations.

The program also has developed 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. The program has conducted operation and evaluation of 10Nm^3/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 provided to relevant ministries data that 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 demonstration systems 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.

Establishment of Organization to Make Use of Results Toward Industry-academia-government Collaboration beyond SIP

Mr. Muraki says, "We have been understood each strength and weakness well while we pushed forward the development of three carriers. In this program, we especially showed the biggest results on utilization technology of Ammonia as CO_2-free fuel. We established The Green Ammonia Consortium to make strategy & policy toward social Implementation. After SIP Program, this consortium plans to be independent and organization opened for global industries, I'd like to promote the technology development, its demonstration and social implementation by the cooperation with overseas companies effectively and systematically.

He says, "It is said that De-carbonization and Decentralization, Digitalization are required from now on. Toward De-carbonization, I think Hydrogen plays an important role and Ammonia is a door opener of Hydrogen Society. Energy diversification is also important. In parallel, it is important to develop a method for Hydrogen utilization in addition to Ammonia toward energy security improvement and industrial capability enhancement."

Even after this five years program finishes, closer cooperation among industries, academia and government will be required to utilize advantage of achievements on this program in the world.

Based on results of SIP, we will work to Introduction and utilization of new CO_2-free fuel for Japan, aiming at the achievement of a low-carbon society.