Development of Environmental Technology

Principle and Outline

The Daigas Group views technology as the foundation for its corporate competitiveness and views research and development as one of its most important strategies for differentiating itself from the competition. While accelerating low-carbon transitions through development of technologies contributing to the reduction of CO_2 emissions, we take on the challenge of technical research and development for the carbon neutrality of our gas and electricity. We will actively tackle a wide range of subjects, from the advanced use of natural gas to the further utilization of renewable energy and the research and development of carbon-neutral gas technologies such as methanation, to accelerate development of technologies that will contribute to achieving carbon neutrality.

Development of New Technologies that Contribute to Carbon-Neutral Solutions

The Daigas Group believes that e-methane*, which is synthesized from hydrogen produced using renewable energy and CO_2, is the key to making city gas carbon-neutral. The Group is working on establishing a variety of methanation technologies toward full-scale introduction of e-methane in 2030. Moreover, we are promoting development of technologies that contribute to further low-carbon/carbon-neutral solutions by making use of the gas synthesis/catalyst technology, combustion technology, and material technology that Osaka Gas has developed so far. For example, the Company is now developing hydrogen and ammonia combustion technologies by leveraging the know-how cultivated through the development of a variety of natural gas combustion technologies tailored to our customers' uses. Such efforts include the development of a small ammonia engine system in cooperation with Toyota Industries Corporation. The Company is also working on the development of chemical looping combustion technology as a technique for producing carbon-neutral hydrogen and electricity from biomass. In addition to energy, Osaka Gas also develops and sells SPACECOOL®, a radiative cooling material. The Carbon Neutral Research Hub of Osaka Gas conducts these researches and development projects, disseminates information, and forms business alliances. To further accelerate these efforts, we are establishing a new research and development base in the Torishima district of Osaka City, with full-scale operations scheduled for FY2026.3

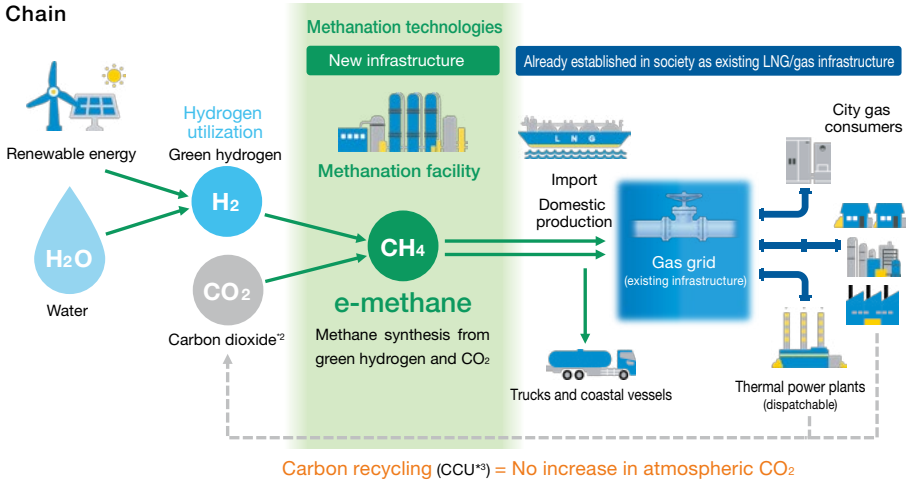
*Synthetic methane produced from non-fossil energy sources, such as green hydrogen, is called "e-methane".

"e-methane"—the key to carbon-neutral solutions created by methanation technology

"e-methane," which is produced by recycling CO_2 otherwise emitted into the atmosphere and synthesizing it with hydrogen, is a carbon-neutral hydrogen carrier*1.

Since "e-methane" has almost the same composition as city gas, existing city gas infrastructure and combustion equipment at customers' sites can be used as is, enabling seamless carbon neutralization during the transition period and advantageously reducing the cost of its social implementation.

■ e-methane Supply Chain



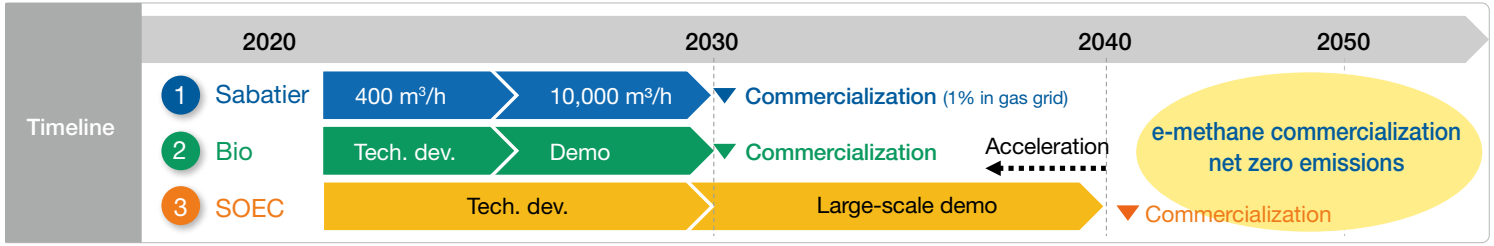
*1 Hydrogen compounds that make it possible to store, transport and use hydrogen efficiently. (Hydrogen is inefficient to store or transport over long distances in its gaseous state.)
*2 Biogenic CO_2 and possibly CO_2 derived from DAC (Direct Air Capture: a technology used to capture and remove CO_2 directly from the atmosphere) might be utilized in the future.
*3 Carbon dioxide Capture and Utilization

Efforts to establish three methanation technologies to enable the introduction of "e-methane"

In addition to working to scale up the existing technology, Sabatier methanation, we aim to commercialize biomethanation, a locally produced and locally consumed energy generation technology, and to achieve early introduction of highly efficient SOEC methanation, an innovative technology.

1. Sabatier methanation*1 (existing technology): Scaled up and implemented in society at an early stage
2. Biomethanation*2 (innovative technology): Produce and use energy locally for local consumption
3. SOEC methanation*3 (Innovative technology): Reduce cost by enhancing energy efficiency

Roadmap for Social Implementation of Methanation Technology



*1 CO_2 conversion by a catalytic reaction with hydrogen derived from renewable energy, etc. to synthesize methane.
*2 Technology that uses biological reactions to synthesize methane from CO_2 and hydrogen
*3 Use of SOEC equipment to electrolyze water and CO_2 into hydrogen and carbon monoxide using renewable energy, etc., and then synthesize methane by catalytic reaction of the hydr ogen and carbon monoxide.

Progress in SOEC methanation development

In 2021, Osaka Gas became the first company in Japan to succeed in creating a full-sized cell prototype for metal-supported SOEC, the key to SOEC methanation technology.

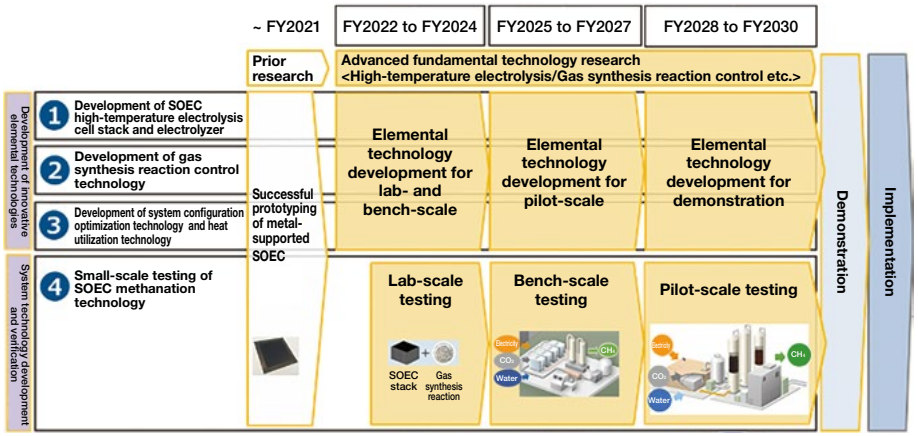
In April 2022, in response to a call for proposals by the National Institute of Advanced Industrial Science and Technology (AIST) and the New Energy and Industrial Technology Development Organization (NEDO), we proposed an SOEC methanation technology innovation project for the “development of innovative technology for the production of synthetic methane,” one of the research and development themes of the Green Innovation Fund Project’s Development of Technology for Producing Fuel Using CO_2, etc. The Group’s proposal was adopted for the project.

The project is expected to take nine years, starting in FY2023.3 and ending in FY2031.3. It will bring together technologies related to SOEC methanation and aims to establish synthetic methane production technologies with the world’s highest levels of energy conversion efficiency.

As a small-scale experiment, from FY2023.3 to FY2025.3, we built a lab-scale pilot facility and confirmed an energy conversion efficiency of 60% or higher.

From FY2026.3 onward, we plan to gradually increase the scale of its experimentation.

SOEC Methanation Technology Innovation Project Schedule



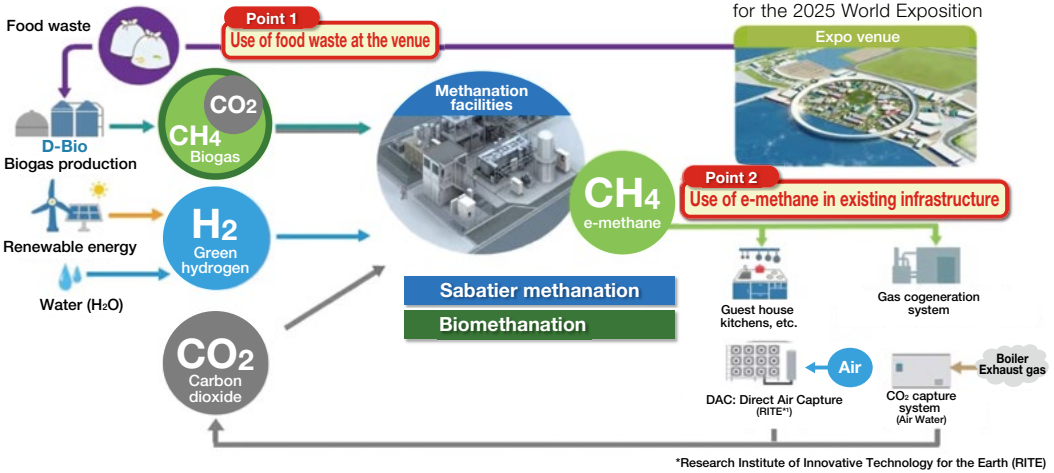
Daigas Group's Development of Carbon Neutrality-Related Technologies to Help Achieve the Theme of the Osaka/Kansai Expo: "Designing Future Society For Our Lives"

Verification of e-methane production within the Expo site

At the site of the Osaka/Kansai Expo (©Expo2025), a demonstration project is being conducted to create e-methane (enough for 170 typical households) by synthesizing CO_2 produced through the fermentation of food waste and other CO_2 to be reclaimed from the site with green hydrogen produced in the site through the methanation.

The generated e-methane is being supplied to gas-powered equipment and used in gas-fired kitchens in the guest house, gas co-generation within heat supply facilities, and gas-powered air conditioning.

■ Conceptual image of demonstration project



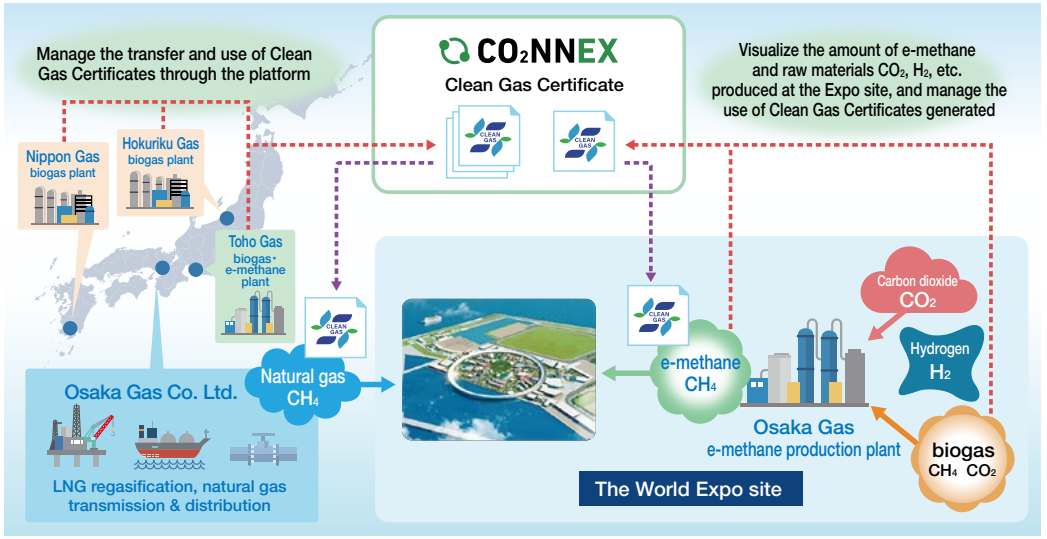
Operation of CO_2 NNEX® that enables the transfer of environmental value of e-methane

As more e-methane is supplied in city gas, private operations have begun for clean gas certificates that can transfer the environmental value of e-methane and biogas, similar to non-fossil certificates for electricity. As the trading volume of e-methane and its environmental value will increase in the future, it will be necessary to have a system for transferring environmental value via clean gas certificates.

Osaka Gas and Mitsubishi Heavy Industries, Ltd., have developed CO_2NNEX®*, the first system in the city gas industry that enables the transfer of the environmental value of e-methane, and is operating this system at the Expo 2025 Osaka, Kansai, Japan. At the Expo, CO_2NNEX® is being used to transfer and use clean gas certificates obtained from e-methane and biogas produced nationwide to natural gas supplied by Osaka Gas, contributing to carbon neutrality within the Expo.

*CO_2NNEX is a registered trademark of Mitsubishi Heavy Industries, Ltd.

■ CO_2NNEX® Clean Gas Certificate Transfer Initiative



Expo site image courtesy of Japan Association for the 2025 World Exposition

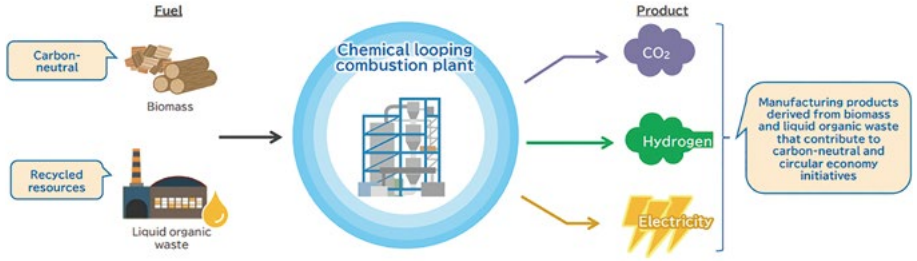
Development of chemical looping combustion technology for simultaneous production of hydrogen, electricity and CO_2

Osaka Gas is working on the development of chemical looping combustion (CLC*1) technology*2, which produces electricity, hydrogen, and CO_2 simultaneously by leveraging the redox action of iron oxide. CLC technology circulates iron oxide to have it react with fuel, water, and air, through which electricity, hydrogen, and CO_2 are produced simultaneously. Biomass and organic waste liquid can be used as fuels. This technology is expected to produce and supply green electricity, hydrogen and biomass-derived CO_2 when carbon-neutral biomass is used as fuel, and electricity, hydrogen, and CO_2 through the recycling of waste materials when organic liquid waste is used as fuel.

Meanwhile, there has been no implementation example of CLC technology aimed at producing hydrogen using biomass or organic waste liquid as fuel. For commercialization, it is necessary to solve technical issues such as elemental technology development toward the establishment of system design technology and process verification. The Daigas Group plans to use this technology to generate electricity, hydrogen, and CO_2 using biomass and organic waste liquid as fuel and to supply them to customers who want to contribute to carbon neutrality and the circular economy.

*1 CLC: Chemical Looping Combustion
*2 NEDO- subsidized project: "Development of Technology for Carbon Recycling and Next-Generation Thermal Power Generation/Development of Fundamental Technologies for Next-generation Thermal Power/ Development of technology for a poly-generation system with CO_2 separation and capture capabilities/ Development of technology for chemical looping combustion poly-generation"

■ Our vision for the practical application of CLC technology



Radiative cooling material SPACECOOL®, a new product by SPACECOOL Inc. —Also contributing to realizing a carbon neutral society with world-class cooling performance—

SPACECOOL®, developed by Osaka Gas and manufactured and sold by SPACECOOL Inc., is a radiative cooling material with zero-energy cooling capability. By releasing heat into space under direct sunlight, it lowers the temperature*1 below the outside temperature without using energy. It has the potential of contributing to carbon-neutral solutions for society as a whole.

A demonstration test confirmed that the temperature inside the structure was up to about 10°C*2 lower than the outside air temperature under direct sunlight, realizing world-class*3 cooling performance.

Courtesy of Japan Gas Association

The material is available in film, magnet sheet, tarpaulins, etc., and is expected to be deployed in products for implementing measures against global warming, achieving energy conservation and ensuring cooling comfort.

It is adopted in the Gas Pavilion exhibited by The Japan Gas Association at the Osaka/Kansai Expo (©Expo2025), reducing the air conditioning burden in the Gas Pavilion and contributing to lower CO_2 emissions. In the future, we would like to promote the spread of this material both domestically and internationally and contribute to the realization of a carbon neutral society.

*1 This has been achieved by using Osaka Gas's proprietary optical control technology to develop a material design that reduces the solar heat input and increases heat dissipation through thermal radiation.
*2 The temperature was measured at Osaka Gas Energy Technology Laboratories (currently, the Advanced Technology Institute) in Konohana-Ward, Osaka City.
*3 The survey was conducted by the Company, based on published papers.

Development of technology for predicting renewable energy power generation

With an eye on the increasing number of renewable energy power plants such as solar power plants to realize a carbon neutral society, the Daigas Group is working to develop technology to predict renewable energy power generation amounts and improve the accuracy of the prediction.

For example, previously, electricity generated in solar power plants was traded at a fixed price, known as FIT. In recent years, a growing number of solar power plants are using schemes other than FIT, as a new purchase method, FIP, has been implemented. Therefore, power producers are increasingly required to predict power generation with a high level of accuracy, given the risk of needing to pay imbalance costs*. The Group has developed technologies for predicting weather at a level comparable to that of weather companies, based on our long-accumulated knowledge of fluid analysis, and has been implementing highly accurate solar power generation predictions utilizing this technology. In the future, solar power generation will be joined by wind power generation, and we will work to further improve the accuracy of our renewable energy power generation forecasts.

* Imbalance costs: Monetary penalties incurred when there is a discrepancy between the planned and actual amount of electricity generated when operating a power plant.

Initiatives to develop the world's first "ultra-long life" storage batteries that last five times longer than current storage batteries

The storage battery market is expected to continue to expand worldwide for multiple applications, such as automotive and stationary use. In Japan as well, storage batteries are positioned as one of the most crucial technologies to achieve the electrification of automobiles and the utilization of renewable energy as the main power source, with a view to achieving the greenhouse gas emissions reduction target for FY2031.3 and carbon neutrality by 2050.

KRI, Inc., one of the Group companies, is a comprehensive private contract research company with both advanced research and development capabilities and consulting functions. The company supports customer businesses by engaging in contract research and analysis evaluation, primarily focusing on energy, environmental technology, and material technology. It also pursues the excavation of new technological seeds and the creation of new value through its own research. In particular, storage batteries are emphasized as one of its key fields of focus, and the company is actively expanding its contract research and development business related to such products. We have been discussing and developing "ultra-long life" storage batteries from two aspects of "materials, electrodes, and batteries" and "diagnosis and operation" with manufacturers who agree on KRI's "ultra-long life concept," with the aim of achieving "ultra-long life," which is the direction of the storage batteries needed for a 2030 society.

Having had the prospect of completing the basic technology for "ultra-long life" lithium ion batteries (LIB)*1 that last five times longer than current storage batteries and reaching its goal, KRI, Inc. starts supplying 10Ah (around 400 Wh/L)*2 samples for user evaluation in FY2026.3. The above assumes the use of prototyping and demonstration technology of SEI CORPORATION, which became a subsidiary of KRI, Inc in February 2024.

Ultimately, the company aims to increase the life of conventional 30 kWh batteries installed in electric vehicles (e.g. 160,000 km guaranteed) by more than five times.

*1 A type of storage battery that uses an oxide containing lithium for the positive electrode and carbon material for the negative electrode. This battery has high performance and can be miniaturized. It is used in a variety of applications, including batteries for mobile devices and electric vehicles.

*2 Approximately the capacity installed in an electric motorcycle.

Launch of demonstration tests of degradation diagnosis and lifespan prediction model for EV storage batteries

In October 2024, Osaka Gas and KRI, Inc. launched demonstration tests of degradation diagnosis and lifespan prediction model for EV storage batteries, using data acquired from electric vehicles used by the Daigas Group ("Company EVs").

The decarbonization of the transport sector, which accounts for just under 20% of Japan's total CO_2 emissions, will play an important role in realizing carbon neutrality by 2050. Increasing the use of EVs has been positioned as an effective means of achieving this, together with the decarbonization of power sources.

The Daigas Group aims to achieve net zero CO_2 emissions from company vehicles by FY2031.3, and began introducing EVs into its company vehicle fleet from August 2024.

However, as the amount of degradation that occurs in storage batteries used in EVs varies depending on their usage environments (ambient temperature, method and frequency of charging and discharging, driving patterns, etc.), identifying the amount of degradation for individual storage batteries and estimating their remaining lifespans and internal state present a challenge to long-term storage battery use.

In these demonstration tests, we collect and analyze data from the storage batteries used in Company EVs to conduct detailed design and accuracy testing in preparation for the commercialization of these estimation technologies.

This will make it possible to visualize the degradation and predict remaining lifespans of individual EV storage batteries in different states and to provide advice if their operating conditions are not adequate. Doing so will promote the long-term use of EVs based on an accurate understanding of individual EV storage battery degradation and remaining lifespans, which has the potential to extend EV lifecycles.

We aim for the practical application of these technologies within the Group by the end of FY2026.3. Subsequently, we will contribute to the expansion of EV leasing and the growth of the used EV market by developing related commercial services.

Going forward, we will apply these technologies to a wider range of businesses that use storage batteries, including the battery energy storage system sector, such as the grid storage battery business that use reused storage batteries.

Development of degradation diagnosis and lifespan prediction technologies for battery energy storage system

Osaka Gas and KRI, Inc. have used KRI's technologies to develop deterioration diagnosis and forecast technology for battery energy storage system for grid storage batteries*3 and other equipment.

In recent years, renewable energy has come to be used more widely, increasing the need for storage batteries that help mitigate the variability in renewable energy output. The Company decided to enter the grid storage battery business in February 2023, and we are currently working on projects at three locations across Japan.

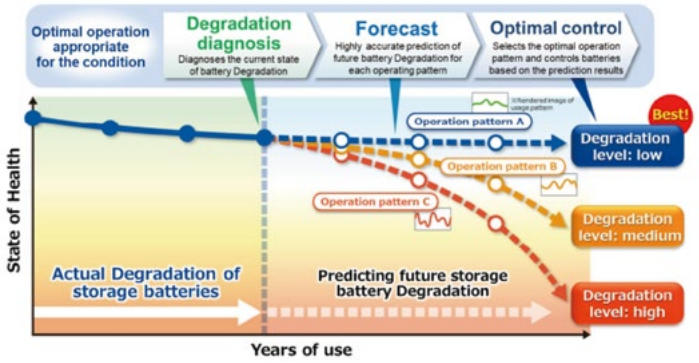
Meanwhile, by their nature, storage batteries can undergo sudden degradation and become less safe if their charging and recharging is not controlled based on their State of Health. For large-scale battery energy storage system, in particular, there has been a need for the development of operation technologies that enable safe, long-term use.

This technology not only diagnoses the State of Health of storage batteries from monitoring data such as in-service voltage, current, and temperature, but also predicts future deterioration for each operating pattern.. Furthermore, combining theoretical models based on physical phenomena with data makes it possible to select optimal operation methods from a wider range of operation patterns, compared to conventional prediction methods that use only data. This has the potential to slow down degradation and allow storage batteries to be used for long periods of time.

Going forward, we will gradually expand our application of this technology to our own storage battery business, and proceed with detailed design work aimed at their practical application. At the same time, we will use this technology and the power trading know-how we have developed to create a system for determining optimal operation of storage batteries to achieve longer storage battery lifespans and greater safety, as well as the economic efficiency of electricity market transactions.

Furthermore, throughout the storage battery business, we will leverage the comprehensive strengths of the Daigas Group to carry out studies not only in the grid storage battery business, which we are already a part of, but also storage batteries installed with renewable energy facilities, with the aim of becoming one of Japan's top storage battery operation companies.

*3 Large-scale storage batteries directly connected to the power grid



Osaka Gas's experimental residential complex, "NEXT 21" won multiple awards

NEXT 21, Osaka Gas's experimental residential complex, was awarded the "Minister of Land, Infrastructure, Transport and Tourism Award in the 44th Green City Award," "the Organization for Landscape and Urban Green Infrastructure President's Award in the 23rd Innovative Green Tech Awards," and "the Good Design Award 2024."

As a verification model for environmentally symbiotic housing, NEXT 21 is continuing its efforts aimed at developing urban housing in which people live in harmony with nature. These awards are a recognition of the results this housing experiment has produced over the past 30 years.

■ Details of major initiatives

- Energy experiments
  Experiments have been carried out regarding efficient energy systems, healthy and comfortable living spaces, disaster-ready housing, and more.
- Environmental symbiosis activities
  Through planting management and the growth of local vegetables in rooftop gardens by residents, the residential complex is continuing its environmental protection activities.
- Community formation
  NEXT 21 is engaging in community-rooted activities such as building illumination, music events, disaster drills, cooking workshops, and more.