

# Energy Solutions for Carbon Neutrality at Municipal Wastewater Treatment Facilities

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At water treatment facilities, there is increasing demand for the reduction of CO<sub>2</sub> emissions in line with the government's policy toward carbon neutrality. Nissin Electric Co., Ltd. provides energy solutions for carbon neutrality at wastewater treatment facilities, such as energy-saving measures and the introduction of renewable energy, as well as energy management systems for the effective use of these solutions. This paper introduces recent energy solutions for wastewater treatment facilities.

Keywords: wastewater treatment facility, carbon neutrality, energy solution, energy savings, renewable energy

## 1. Introduction

Japan aims to reduce greenhouse gas emissions by 46% from 2013 levels by 2030 and achieve carbon neutrality by 2050.

In fiscal year 2021, greenhouse gas emissions from wastewater treatment facilities amounted to approximately 5.2 million tons (Fig. 1),<sup>(1)</sup> accounting for approximately 0.5% of Japan's total greenhouse gas emissions and absorption (1.122 billion tons).<sup>(2)</sup> Furthermore, wastewater treatment accounts for a significant portion of greenhouse gas emissions among municipal administrative operations. Therefore, achieving carbon neutrality at wastewater treatment facilities is essential for municipalities to meet their emission reduction targets.

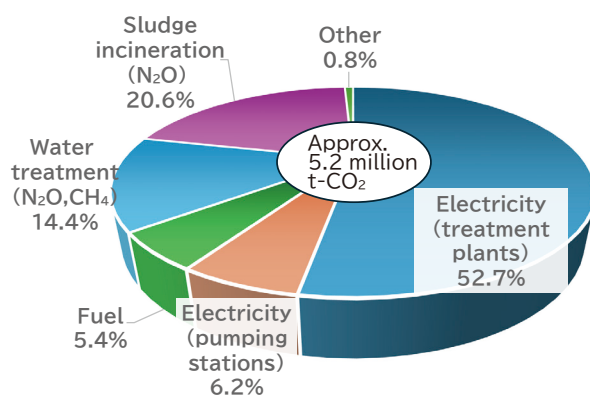


Fig. 1. Greenhouse gas emissions from wastewater treatment facilities (FY 2021)

## 2. Efforts to Achieve Carbon Neutrality at Wastewater Treatment Facilities

Various initiatives are being undertaken to achieve carbon neutrality at wastewater treatment facilities. The status of key initiatives, along with challenges and countermeasures, are described below.

### 2-1 Reducing energy consumption

Many wastewater treatment facilities are aging, raising concerns about declining energy efficiency and

increased accident risks. The planned renewal of aging facilities is an urgent task, and achieving carbon neutrality must also be considered during facility replacements. To reduce energy consumption, efforts are advancing beyond the introduction of the latest energy-saving equipment and replacement with high-efficiency equipment. These include optimizing equipment control (such as pump operation), developing and introducing new energy-saving control systems through operational method reviews, optimizing operating conditions and loads, and adopting the latest energy-saving technologies.

### 2-2 Introduction of renewable energy

By introducing renewable energy (RE) into wastewater treatment facilities, such as solar power generation using idle land on-site or power generation utilizing biogas generated during sludge treatment, energy self-sufficiency is being enhanced, reducing electricity load and cutting carbon dioxide (CO<sub>2</sub>) emissions.

### 2-3 Smart operation and energy management

The declining birthrate and aging population are causing a severe shortage of skilled technicians and next-generation operators. This hinders the succession and streamlining of wastewater treatment facility operations, as well as technological innovation, making the transfer of existing technical expertise a critical challenge. Consequently, the development and market introduction of technologies that pursue optimal energy use and improve energy management efficiency are gradually advancing through monitoring, control, and maintenance systems utilizing information and communication technology (ICT) and artificial intelligence (AI). Examples include operation support units that promote efficient operation, AI-based energy management, and asset management based on equipment operation data.

## 3. Reducing Electricity Consumption in Wastewater Treatment Facilities

Figure 2 shows the breakdown of electricity consumption by facility type in wastewater treatment facilities.<sup>(1)</sup> Water treatment equipment (Fig. 3) accounts for a high proportion of total electricity consumption at 45%.

Reducing electricity consumption here is effective for lowering overall electricity consumption in wastewater treatment facilities. Measures include energy-saving operation of wastewater treatment facilities and optimizing aeration control.

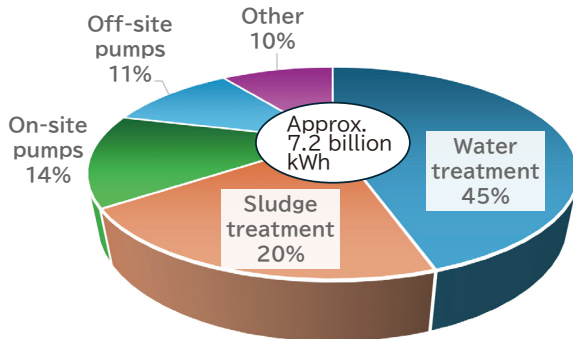


Fig. 2. Breakdown of electricity consumption by facility type at wastewater treatment facilities (FY 2021)

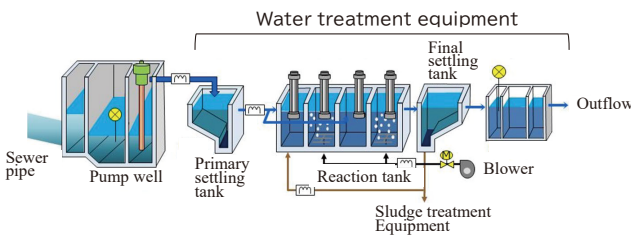


Fig. 3. Water treatment equipment at wastewater treatment facility

### 3-1 Energy-efficient operation of water treatment equipment

The Ministry of Land, Infrastructure, Transport and Tourism’s “New Sewerage Vision Acceleration Strategy”<sup>(3)</sup> emphasizes thorough cost reduction through the adoption of energy-saving technologies as part of efforts to ensure sound sewerage management. It promotes energy conservation while maintaining appropriate treated water quality.

This section introduces energy-saving operation technologies proposed by Nissin Electric Co., Ltd.

#### (1) Intermittent operation of submerged mixer

Submerged mixers in reaction tanks prevent the settling of activated sludge\*<sup>1</sup> and promote effective contact between wastewater and the activated sludge. Generally, submerged mixers consume significant power. Therefore, during periods of high wastewater inflow or when a certain level of mixing effect can be expected within the reaction tank, intermittent operation of the submerged mixers can help maintain water quality while reducing power consumption. Figure 4 illustrates the concepts of continuous and intermittent operation for submerged mixers. Actual operation schedules should be set based on the temporal characteristics of the expected mixing effect, estimated from operating conditions such as influent flow rate and aeration volume.

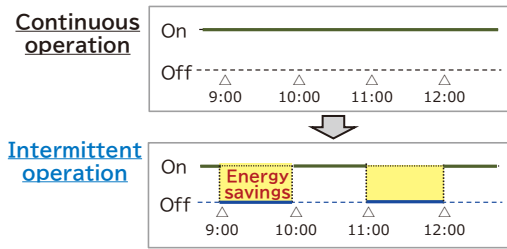


Fig. 4. Continuous and intermittent operation of submerged mixer

#### (2) Adjusting rotational speed of submerged mixer

If the submerged mixer does not support intermittent operation, energy savings can be achieved by adjusting the mixer’s rotational speed based on the mixing state within the reaction tank. For example, during periods with high wastewater inflow where consistent mixing effects can be expected within the reaction tank, operation at a lower rotational speed than normal is possible, thereby reducing power consumption (Fig. 5).

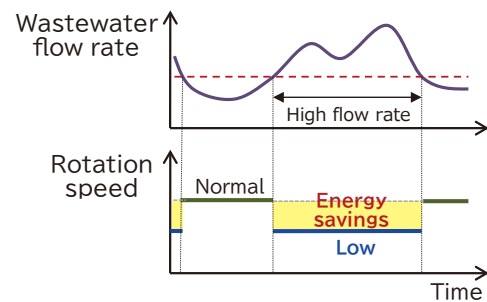


Fig. 5. Adjustment of submerged mixer rotation speed based on wastewater inflow volume

#### (3) Adjusting flow rate of circulation pump

Recirculating nitrification-denitrification processes and anaerobic-anoxic-oxic processes are known as wastewater treatment methods for biologically removing nitrogen components from wastewater. In these methods, a recirculation pump operates to return mixed activated sludge water from the downstream to the upstream side of the reaction tank. Theoretical nitrogen removal efficiency

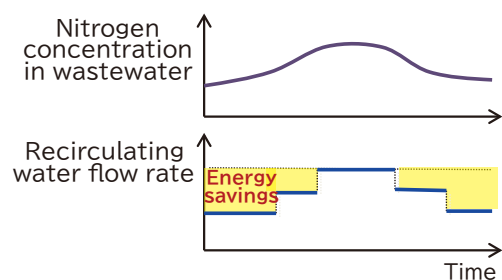


Fig. 6. Adjustment of recirculation flow rate based on nitrogen concentration in wastewater

increases with higher recirculation flow rates. Therefore, the flow is operated to be approximately equal to or greater than the wastewater inflow rate to the reaction tank. Consequently, adjusting the recirculation flow rate based on the nitrogen concentration in the wastewater is expected to stabilize treated water quality and reduce pump energy consumption. Specifically, during periods of low nitrogen concentration in the wastewater (Fig. 6), the flow can be reduced, allowing for sufficient treated water quality even with a lower nitrogen removal rate. This enables both the maintenance of treated water quality and energy savings.

(4) Intermittent operation of defoaming water pump

Foam formation in reaction tanks can lead to deterioration of treated water quality and the generation of foul odors. Therefore, defoaming water pumps are generally continuously operated to suppress foam generation and expansion. The factors causing foam formation and its severity vary depending on the season, time of day, operating conditions, and other factors. Therefore, by adjusting the operation of the defoaming water pump—such as incorporating intermittent operation—based on the foam formation trends and characteristics at each wastewater treatment facility, it is possible to reduce pump power consumption. Figure 7 shows the concept of continuous and intermittent operation of defoaming water pump.

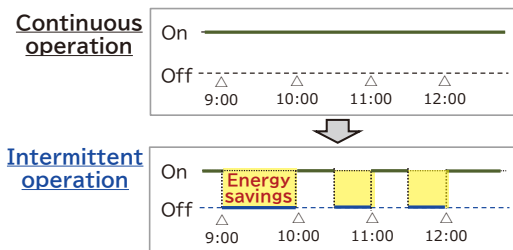


Fig. 7. Continuous and intermittent operation of defoaming water pump

3-2 Aeration control using ammonia meters

Wastewater treatment facilities consume significant electricity for aeration in the reaction tank. In particular, the nitrification\*2 of ammonia nitrogen (NH<sub>4</sub>-N) requires a large aeration volume. Therefore, optimizing aeration volume while maintaining treated water quality to achieve energy savings is a critical challenge. Nissin Electric Co., Ltd., in collaboration with the Japan Sewage Works Agency (JS) and Nissin Systems Co., Ltd., has already developed technology that optimally controls aeration volume using an ammonia meter (NH<sub>4</sub>-N meter) that continuously measures NH<sub>4</sub>-N concentration in water. This section provides an overview of this technology.

(1) Control method

This technology combines feedforward control based on measurements from an NH<sub>4</sub>-N meter installed upstream in the reaction tank (first part NH<sub>4</sub>-N concentration) with feedback correction based on measurements from an NH<sub>4</sub>-N meter installed downstream (latter part NH<sub>4</sub>-N concentration) to automatically control the aeration volume in the reaction tank. This technology targets treatment

facilities using the activated sludge process\*3 (OD method\*4 excluded). Figure 8 shows an overview of this control technology. This technology has been selected as a New Technology under the JS New Tech Implementation Program as the “Feedforward Aeration Control by Ammonia Sensor.”\*(4),(5)

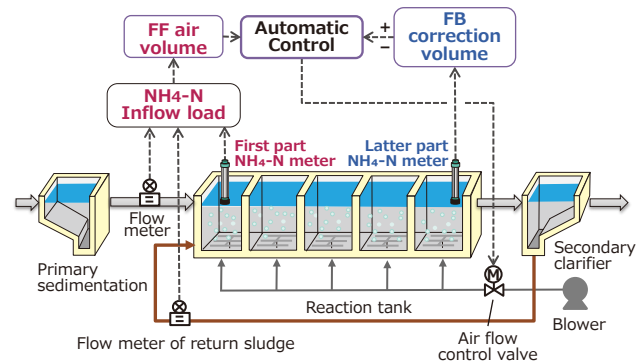


Fig. 8. Overview of aeration control technology by ammonia sensor

(2) Technical features

Figure 9 shows conceptual diagrams of a comparison between conventional technology (constant DO control\*5) and this technology regarding latter part NH<sub>4</sub>-N concentration and aeration in relation to fluctuations in NH<sub>4</sub>-N inflow load.\*6 Conventional technology tends to oversupply air relative to oxygen demand because it controls aeration to maintain target dissolved oxygen (DO) levels even during periods of low influent load. Conversely, when influent load increases sharply, control lag can cause insufficient aeration, potentially leading to incomplete nitrification. In contrast, this technology employs feedforward control that dynamically adjusts aeration in real-time based on NH<sub>4</sub>-N inflow load as an indicator. This enables the aeration volume to appropriately follow fluctuations in the required oxygen demand. Furthermore, by feedback-correcting the aeration volume based on the deviation between the measured value and the target value downstream, latter part NH<sub>4</sub>-N concentration can be maintained at the target value.

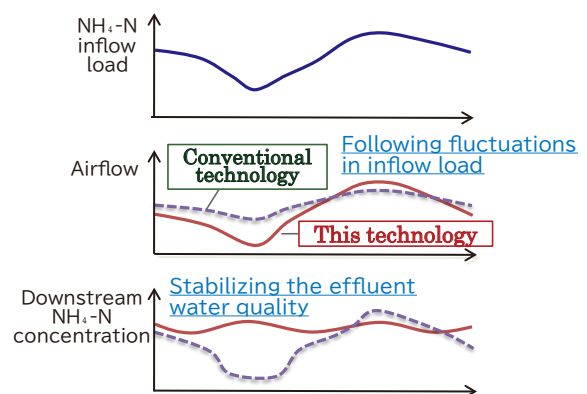


Fig. 9. Comparison of aeration control technology by ammonia sensor and conventional technology (conceptual diagram)

(3) Implementation effects

This technology is expected to reduce aeration volume by approximately 10% or more compared to conventional methods, thereby reducing the power consumption of blowers. However, the detailed power reduction effect depends on blower specifications, power characteristics, operating conditions, and other factors. Furthermore, by correcting the aeration volume based on the latter part NH<sub>4</sub>-N concentration, it stabilizes the NH<sub>4</sub>-N concentration in the treated water.

4. Introduction of RE and Effective Resource Utilization

4-1 Solar power generation

With the decline in inflow volume due to population decrease, it is anticipated that the development plan of treatment plants will be reviewed, leading to an increase in idle and unused land. By installing solar panels in these areas, as well as on treatment building rooftops and the upper sections of water treatment facilities, and utilizing the electricity generated there within the facility, CO<sub>2</sub> emissions can be reduced. Installation atop water treatment facilities also contributes to suppressing algae growth and preventing foreign object ingress. However, since the timing when the treatment plant requires electricity and when the solar panels generate electricity may differ, waste could occur depending on the situation. To counter this, installing storage batteries for charging and discharging can reduce power waste and enable more effective electricity usage (Fig. 10).

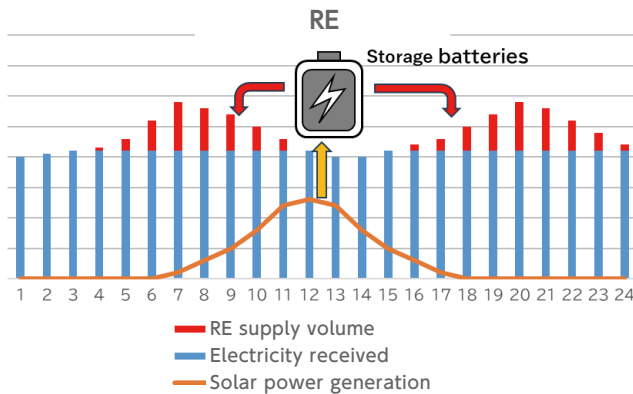


Fig. 10. Peak cutting using solar power generation and storage batteries

4-2 Digester gas power generation

Wastewater sludge collected at wastewater treatment facilities is fed into thickened digestion tanks. Within these tanks, digester gas is produced through microbial activity. This digester gas is a combustible mixture containing methane (CH<sub>4</sub>) and CO<sub>2</sub>, and cannot be released into the atmosphere (CH<sub>4</sub> has 25 times the greenhouse effect of CO<sub>2</sub>). Therefore, traditionally, digester gas was either used as boiler fuel to heat the digestion tanks or incinerated. Digester gas can be used as fuel for generators by

employing dedicated generators. Furthermore, the waste heat generated during the power generation from digester gas can be collected and used to heat the digestion tanks (Fig. 11), or utilized as a heat source for cooling, heating, and hot water supply.

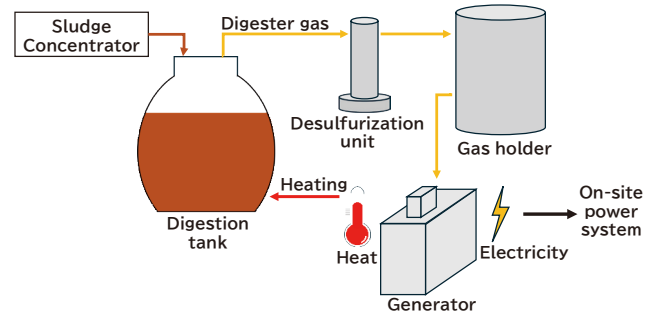


Fig. 11. Configuration diagram of power generation using digester gas system

Additionally, since digester gas can be stored in gas holders, it enables more effective power generation by utilizing it when the treatment plant requires electricity or heat (Fig. 12).

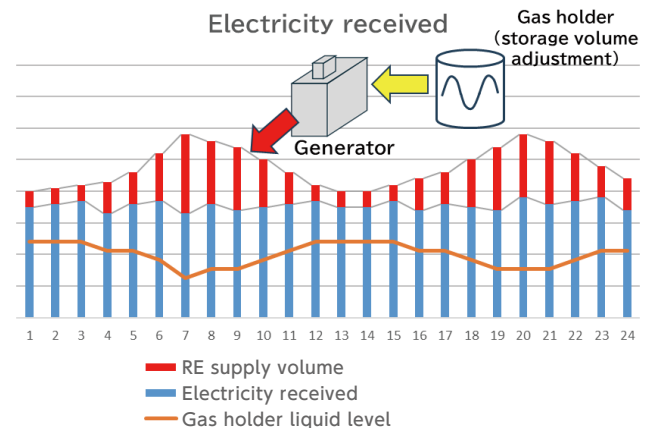


Fig. 12. Power generation using digester gas stored in gas holders

Furthermore, since wastewater sludge qualifies as “biomass,” the CO<sub>2</sub> emitted when using digester gas is not considered a greenhouse gas. Therefore, utilizing this power generation at wastewater treatment facilities can also contribute to carbon neutrality.

Below is a case study of introducing digester gas power generation at the Kizugawa-joryu Purification Center (hereinafter Purification Center) of the Kyoto Prefecture Kizugawa-joryu Upper Stream Watershed Sewerage System.<sup>(6)</sup> The Purification Center began operations in 1999, Target area the Kizu River upper basin (Kizugawa City, Seika Town). Seika Town, where the Purification Center is located, is situated within the Kansai Science City, a cluster of private corporate research bases. With the increase in corporate and residential development

within the city, the inflow of wastewater to the Purification Center has also been on an upward trend. As of the end of fiscal year 2019, the population served was 90,958, and the treatment capacity was 32,280 m<sup>3</sup>/day. The Purification Center introduced four digester gas power generation units (Photo 1), in 2015 and three more in 2021. These units utilize methane gas (digester gas) generated during the wastewater treatment process. Utilizing a total of seven digester gas power generation units is expected to yield the following benefits:

- (1) Annual biogas power generation is projected to be approximately 1.5 million kWh, equivalent to the annual electricity consumption of about 500 households. Using all this power within the Purification Center will cover about 25% of the center's annual electricity consumption and reduce greenhouse gas emissions by approximately 510 tons.
- (2) Waste gas generator exhaust heat can be utilized for heating digestion tanks, which previously used hot water boilers. By measuring the temperature inside the digestion tanks and the temperature of the heating water, the adequacy of the heat output is evaluated. If insufficient, the hot water boiler provides supplementary heating, ensuring stable digestion processes.



Photo 1. Equipment of power generation using digester gas at Kizugawa-joryu Purification Center

## 5. Smartification through Digital Technology

Energy consumption at wastewater treatment facilities is substantial, making energy management critically important. Efficient energy management not only significantly reduces energy costs but also contributes to mitigating global warming by reducing greenhouse gas emissions. Furthermore, it promotes resource efficiency, such as utilizing digester gas generated during sludge treatment as a RE source.

Moreover, Japan faces challenges of optimizing facility maintenance efficiency and reducing staffing due to population decline. Therefore, through digitalization, it is necessary to implement AI-powered automated control and degradation diagnostics based on equipment operation data analysis, thereby advancing the development of planned

equipment maintenance and renewal strategies. Here, we introduce an example of smart energy management and asset management through integration with central monitoring and control systems, as implemented by Nissin Electric Co., Ltd.

### 5-1 Operation support unit promoting efficient operation

The nitrification control system utilizing the previously mentioned NH<sub>4</sub>-N meter achieves energy-saving operation by linking an operation support unit—equipped with inflow load analysis support, aeration volume setting support, and target value output functions—with the monitoring and control system (Fig. 13).

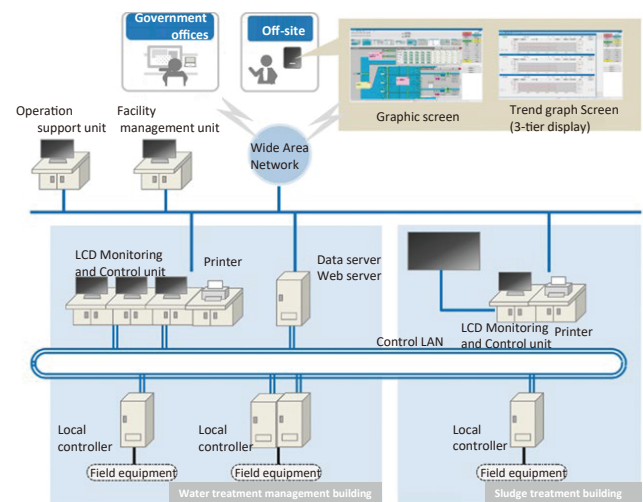


Fig. 13. Example configuration of monitoring and control system

The operation support unit collects actual data such as various flow rates, NH<sub>4</sub>-N concentration, and aeration volume, automatically displaying the relationship between the NH<sub>4</sub>-N inflow load into the reaction tank and the aeration volume. Based on the graph displayed here, control coefficient settings can be made, and the operating status and treatment status can be confirmed.

### 5-2 Energy management utilizing AI

The Water Pollution Prevention Act establishes discharge standards for effluent from wastewater treatment facilities, with chemical oxygen demand (COD) being a regulated parameter. In specific regions such as the Seto Inland Sea, wastewater treatment facilities are subject to additional regulations regarding total nitrogen (TN) and total phosphorus (TP). Treatment plants monitor these parameters using automated measurement devices. However, the treated water quality can deteriorate depending on the quality of the incoming wastewater and the status of the wastewater treatment process. Restoring degraded water quality to normal conditions requires the experience and expertise of maintenance personnel and takes a certain amount of time. Therefore, if AI can predict future water quality fluctuations based on previous performance data and thus maintenance personnel can proactively prevent water quality deterioration, the burden on such

personnel could be reduced. Nissin Electric Co., Ltd. has developed such technology and is implementing initiatives to improve operational management efficiency (Fig. 14).<sup>(7)</sup>

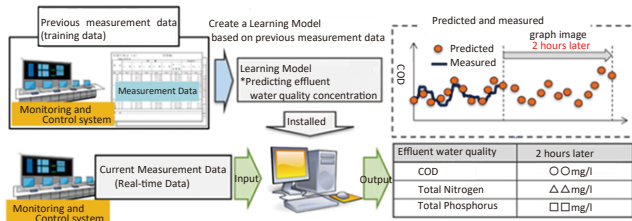


Fig. 14. Development of effluent water quality prediction technology using AI

### 5-3 Asset management based on equipment operation data management

The rate of deterioration in electrical equipment varies depending on the installation environment, making it crucial to constantly monitor and understand environmental conditions. Nissin Electric Co., Ltd. has commercialized a composite environmental sensor (Fig. 15) that digitizes and collects data on the installation environment of field equipment, and is developing deterioration diagnosis technology through data analysis.<sup>(8)</sup>



Fig. 15. Commercialized composite environmental sensor

Nissin Electric Co., Ltd.'s monitoring and control system features various data link functions, enabling linkage with the operational data from the composite environmental sensor. Furthermore, integrating this monitoring and control system with a facility management system that includes a facility management ledger function for registering equipment information at wastewater treatment facilities, and a facility comprehensive management unit that supports report generation by organizing daily on-site equipment inspection tasks and results in a database, facilitates the integration, linking, cross-referenced search, and analysis of various data (Fig. 16). Based on analysis results, it supports planned inspections and maintenance planning, formulates asset management plans, and promotes the

renewal of aging equipment, thereby advancing the achievement of carbon neutrality.



Fig. 16. Collaboration between monitoring and control system and facility comprehensive management unit

## 6. Conclusion

This paper introduces energy solutions for achieving carbon neutrality in wastewater treatment facilities, focusing on energy-saving control technologies for water treatment equipment, RE adoption, effective utilization of resources derived from wastewater, and smartification leveraging digital technologies. Realizing a decarbonized society requires not only adopting energy-saving equipment through facility renewal and implementing energy-saving controls but also expanding RE adoption. It is essential to effectively utilize RE to optimize social costs.

It is crucial to adopt a holistic optimization approach that considers not only environmental impact but also safety and economic feasibility, encompassing diverse initiatives. Nissin Electric Co., Ltd. is also advancing the development of environmentally conscious products not covered in this paper, as well as systems suited for utilizing RE sources and storage batteries. We remain committed to relentless research and development to provide optimal solutions that meet societal needs.

### Technical Terms

- \*1 Activated sludge: Sludge containing microorganisms that consume and decompose pollutants such as organic matter, nitrogen, and phosphorus in wastewater.
- \*2 Nitrification: The process by which ammonia nitrogen (NH<sub>4</sub>-N) in water is oxidized by microorganisms into nitrite nitrogen (NO<sub>2</sub>-N) and then into nitrate nitrogen (NO<sub>3</sub>-N).
- \*3 Activated sludge process: A water treatment method that utilizes activated sludge to purify wastewater.
- \*4 OD process: Oxidation Ditch Process. An activated sludge process that does not use a primary settling tank but instead employs a shallow-depth circulating channel as the reaction tank.
- \*5 Constant DO Control: A technology that automatically controls the airflow rate to maintain a constant concentration of dissolved oxygen (DO) in the reaction tank.
- \*6 Inflow load: The quantity of pollutants entering a wastewater treatment facility or reaction tank.

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