Development of Hydrogen-Based Distributed Energy System

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In order to promote the spread of renewable energy and the use of hydrogen in various ways worldwide, it is important to develop locally distributed energy system that utilizes hydrogen in addition to a global hydrogen and ammonia value chain. This report describes the features and issues of hydrogen-based distributed energy, and introduces recent examples of IHI's activities, such as the development of a "water electrolysis-based energy management system" in the Hibikinada area of Kitakyushu in Japan.

1. Introduction

Reducing greenhouse gas (GHG) emissions in energy use is an urgent issue to realize a sustainable society, and in recent years, efforts to do so have been accelerating dramatically. In October 2020, the Japanese government declared that Japan will achieve carbon neutrality by 2050, and as a specific strategy, the "Green Growth Strategy Through Achieving Carbon Neutrality in 2050(1)" was formulated in December 2020. This strategy presents 14 growth industries in 3 fields — namely, energy-related industries, transport-and-production-related industries, and household-and-office-related industries — with goals and schedules per industry. At the Leaders Summit on Climate held in April 2021, where each country announced their nationally determined contribution (NDC) to reducing GHG emissions, Japan announced a policy of raising its NDC from 26 to 46% relative to 2013 levels by 2030. In this way, efforts to reduce GHG emissions are being connected to each country's economic policies, and we are required to further accelerate our efforts.

Under the Green Growth Strategy, reference values for energy mixes are presented for achieving carbon neutrality. A goal of the power sector is to cover 50 to 60% of power generation with renewable energy, and 10% with hydrogen (H_2) and ammonia (NH_3). A goal of the non-power sector is to achieve carbon neutrality with hydrogen, methanation, and synthetic fuel. As just described, in Japan it is required to spread and expand the use of renewable energy as well as to apply to various fields the technologies of carbon recycling, CCU (Carbon dioxide Capture and Utilization)(2), and various others in order to utilize captured carbon dioxide (CO_2) with hydrogen (ammonia as an energy carrier) as a resource for the purpose of achieving total carbon neutrality.

2. Distributed energy using hydrogen

In order to promote the global spread of renewable energy and multifaceted use of hydrogen, it is important to establish global hydrogen and ammonia value chains while establishing hydrogen-based distributed energy systems in each region.

Distributed energy is a collective term for relatively small-scale energy distributed over different geographical areas(3). Distributed energy has recently been attracting attention because it enables the effective use of renewable energy, which requires supply and demand adjustment, through local production for local consumption, regional revitalization through the effective use of regional resources and industrial development, and emergency energy supply in case of increasingly severe disasters. Distributed energy has various other advantages as well. At the Soma IHI Green Energy Center (SIGC), which opened in 2018, for example, power supply and demand can be balanced within the community, and there are facilities available to supply electricity to neighboring shelters in the event of a power failure (e.g., due to a large-scale disaster)(4). Germany's Stadtwerke, or municipal utility companies which provide community-based comprehensive infrastructure services, including energy supply, are well known, and in Japan as well as other countries, initiatives aiming to make use of various energy sources have been launched(5). **Figure 1** shows the number of energy sources used as distributed energy in Japan by type. This graph is based on the list of cases supported by Japan's environmental ministry for which the energy type has been identified based on disclosed information.

A feature of distributed energy is that assorted devices are combined to handle various local energy sources and demand. **Table 1** lists the typical elements that constitute distributed energy. This table contains energy sources, types of demand, and major system components for distributed energy. Generally, locally produced renewable energy is used as a main energy source, and it is also important to utilize other distributed power sources, such as co-generation, and to connect them to the grid. The supply side is required to meet local demand, and it is necessary to contribute to the

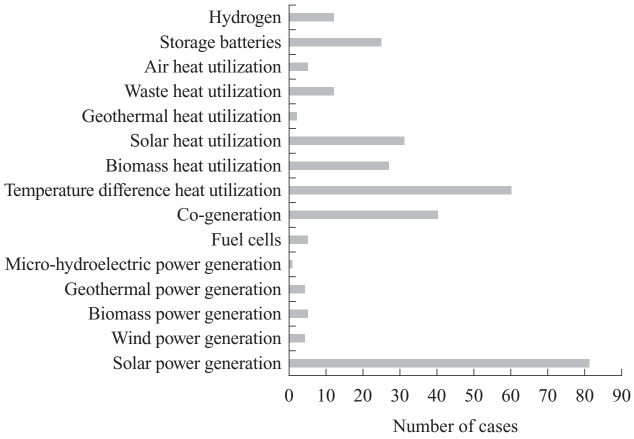

Fig. 1 Number of energy sources used as distributed energy in Japan[5]

Table 1 Examples of components of distributed energy

Item	Major elements
Energy source	Renewable energy (solar power, wind power, geothermal power, biomass, etc.), co-generation (gas engines, gas turbines, fuel cells, etc.), grid power, etc.
Demand type	Electric power, heat, gas, raw materials, services, etc.
System component	Generators (co-generation, fuel cells, etc.), energy storage devices (storage batteries, heat storage, etc.), converters (for heat, hydrogen from water electrolysis, hydrocarbon (methane and olefin), etc.), CO_2 capture equipment (with amine method, DAC, etc.), EMS

community by supplying not only electricity but also heat, fuel, raw materials as well as incorporating them into various services, including BCP (Business Continuity Planning). As system components for connecting the supply side with the demand side, in addition to hardware (including generators, various energy storage devices, and converters), software (including energy management systems (EMS), which are used to control hardware components in an integrated manner) is required.

The authors consider that, among the systems listed in **Table 1**, hydrogen-based distributed energy systems will become mainstream for the following reasons. **Figure 2** is a conceptual diagram of a distributed energy system using hydrogen. Because hydrogen can be used as a fuel, it can be used directly, for example, for fuel cell vehicles (FCV). Moreover, it can be a means of energy storage and makes it possible to generate and supply electricity with fuel cells in the event of an emergency or disaster. Also, hydrogen serves as a reducing agent and can be used as a raw material for CCU, such as methanation[6]. With hydrogen, various hydrocarbons can be synthesized. In this way, use of hydrogen significantly increases the applications of renewable energy, which makes it possible to enhance the added value of renewable energy and to meet various types of local demand. With regard to carbon recycling specifically, hydrocarbons (e.g., methane (CH_4)) can be synthesized by reacting hydrogen with carbon sources (e.g., carbon monoxide (CO) and CO_2) with the use of catalyst. Because loss always accompanies conversion, unnecessary conversion should be avoided, but we think that offering a system to convert local renewable energy into various products and services according to local demand will promote the introduction of distributed energy, leading to greater use of renewable energy and hydrogen.

3. Challenges of hydrogen-based distributed energy systems

The challenges of hydrogen-based distributed energy systems include optimization of the entire system and control, reduction of hydrogen costs, and sophistication of conversion technology.

3.1 Optimization of the entire system and control

The most important thing is to identify local renewable energy sources, needs, and types of demand as well as to determine the optimal system and control method according to these elements. In some regions, in addition to solar power, various renewable energy sources (e.g., wind power, hydraulic power, geothermal power, and biomass) are available. Because renewable energy-derived electric power may be purchased, grid interconnection must be considered. With regard to the types of demand, those other than use as electric power must also be considered. Conventionally, heat tends to be unused because it cannot be stored or transported easily, but in distributed energy, heat is an important energy medium. In addition, hydrogen itself and fuels and raw materials synthesized from hydrogen are considered to be

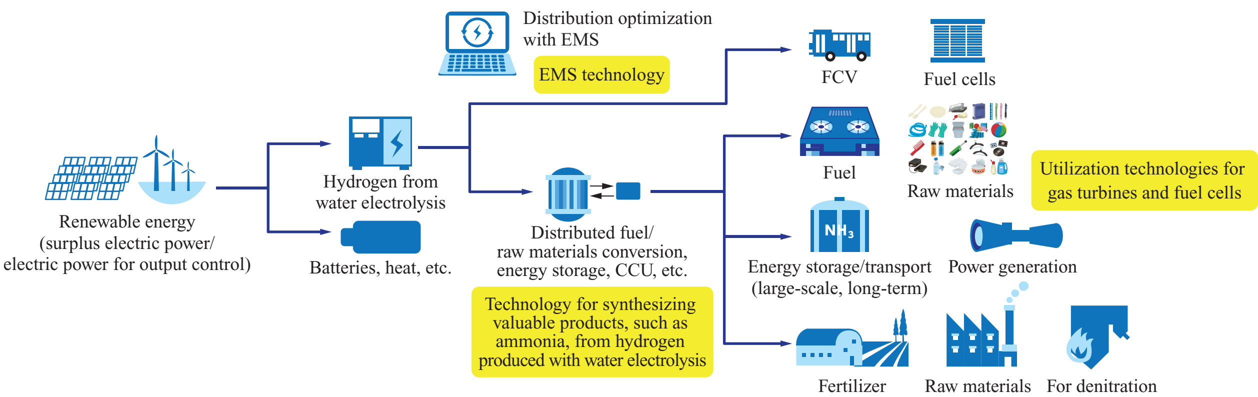

Fig. 2 Conceptual diagram of hydrogen-based distributed energy system

types of demand. Combining these types of demand with high-value-added services will make it possible to establish an economically feasible system.

As just described, after identifying the supply side and demand side, there is a need to study the optimal system hardware for connecting the supply side with the demand side. As shown in **Table 1**, the system has various options of components; therefore, there is a need to find the optimal combination to maximize cost reduction and energy savings. In addition to hardware optimization, there is a need to develop an EMS to optimize each component's operation. For example, consider what surplus power should be used for to increase added value when power demand falls below supply. If it should be used to produce hydrogen or to synthesize fuel from hydrogen, consider a control that gives priority to supplying electric power to the water electrolyzer in order to produce hydrogen.

When studying the system, use of hydrogen should not always be included. If using hydrogen does not lead to optimal distributed energy for a given region, consider removing hydrogen from the system components.

3.2 Reduction of hydrogen costs

As described in **Section 3.1**, by using a water electrolyzer, hydrogen can be produced using electric power generated from renewable energy. **Table 2** lists the major features of water electrolyzers. Water electrolyzers are classified into several types according to the type of electrolyte; typical examples include alkaline water electrolyzers, which use an alkaline solution, and PEM water electrolyzers, which use a polymer electrolyte membrane (PEM). Alkaline water electrolyzers are suitable for large-scale use, while PEM water electrolyzers have excellent load responsiveness. An appropriate water electrolyzer must be selected according to the required specifications. In recent years, solid oxide water electrolysis technology, which can work at high temperatures, and co-electrolysis technology, which reduces water (H_2O) and CO_2 to generate $CO + H_2$ gas and other substances, have been developed.

One challenge to be solved to produce hydrogen by water electrolysis is the high cost. Normally, the power consumed to produce hydrogen by water electrolysis is said to be 5 kWh/Nm^3-H_2. So, for example, when the electric power unit price is 5 yen/kWh, the hydrogen cost is 25 yen/Nm^3-H_2. In addition, equipment costs for water electrolyzers are high, and the total production cost using water electrolysis is far higher than that of using fossil fuels, such as steam reforming natural gas. The cost of hydrogen production using water electrolysis can be reduced mainly by ① purchasing cheaper electric power, ② improving the performance of water electrolyzers (improving conversion efficiency), ③ reducing the equipment costs of water electrolyzers, and ④ improving capacity factor. In particular, with regard to the electric power generated by solar energy and wind energy, output fluctuates, and during nighttime, electric power cannot be generated by solar energy. If a water electrolyzer is connected directly to solar power generation or wind power generation, the load of the water electrolyzer fluctuates constantly; as a result, capacity factor decreases, or hydrogen production costs are more affected by equipment costs. In order to improve the capacity factor of water electrolyzers, there is a need to maximize the time during which water electrolyzers operate at maximum load by means of energy storage (e.g., storage batteries).

3.3 Sophistication of conversion technologies

Water electrolyzers are a conversion technology, but in distributed energy, other technologies to convert hydrogen and CO_2 into hydrocarbons are also important. As described in **Chapter 2**, it is expected that synthesizing hydrocarbon by reaction between hydrogen and CO_2 will increase the value of electric power generated from renewable energy as well as increase the potential to meet local demand. This technology is commonly called CCU technology, with which carbon can be recycled by allowing the CO_2 captured from a CO_2 emission source and hydrogen generated by using renewable energy to react back into hydrocarbon. Replacing conventional fossil fuels with fuels and raw materials synthesized from hydrogen and CO_2 in this way can contribute to reducing overall CO_2 emissions.

CCU technology includes CO_2 capture, hydrogen production, and hydrocarbon synthesis technologies. CO_2 capture technologies include the chemical conversion method and the oxygen combustion method. Recently, DAC (Direct Air Capture) and other technologies to capture CO_2 from the atmosphere have been developed. Hydrogen production technologies using water electrolysis have been described in **Section 3.2**. Catalyst and reactor technologies

Table 2 Features of major water electrolyzers

Type	Alkaline water electrolysis	PEM (Polymer Electrolyte Membrane) water electrolysis	SOEC (Solid Oxide Electrolysis Cell) water electrolysis	PCEC (Proton Ceramic Electrolysis Cell) water electrolysis	(Reference) CO_2 water co-electrolysis
Electrolyte	KOH solution	Solid polymer	Solid oxide	Proton-conducting oxide	Solid oxide type/proton type
Operating temperature	50°C	100°C	700 to 800°C	400 to 600°C	High temperature
Efficiency	Low	Medium	High	High	As an application of water electrolysis, CO_2 and water are reduced at the same time to produce $CO + H_2$ and to produce methane and other materials with catalysis. Fundamental research level
Upsizing	Easy	Possible	Not impossible	Not impossible	
Cost	Low	Medium	—	—	
Remarks	Technically mature Water is mixed into hydrogen.	Good load responsiveness Platinum is used as the catalyst. The compact type is ready for mass production, but the large type is at the demonstration level.	Demonstration level Water is mixed into hydrogen.	Fundamental research level	

constitute the core of hydrocarbon synthesis technologies. Development of catalyst for synthesizing methane and olefin[6] is underway, which uses exothermic reaction and therefore requires a reactor technology to appropriately control the catalyst temperature. In order to increase the system scale in the future, systemization technologies to efficiently synthesize a large amount of hydrocarbon with renewable energy-derived electric power, including larger reactors and thermal management of the system, are required.

4. Examples of hydrogen-based distributed energy systems

IHI is carrying out several demonstration projects for hydrogen-based distributed energy systems. **Figure 3** shows the locations of the projects described below.

At the SIGC, the electric power generated by a mega solar farm is used at the sewage disposal plant or converted to heat, which is then used to dry sewage sludge. In addition, this electric power is used to produce hydrogen for hydrogen-related research with a water electrolyzer[7], [8]. Currently, a pilot-scale methanation test is underway, and the target gas composition and CO_2 conversion rate have already been achieved.

Fig. 3 Locations of demonstration projects

In addition, with the aim of developing a hub for producing and supplying CO_2-free hydrogen, which is next-generation clean energy, we have started a demonstration project for producing, transporting, and utilizing hydrogen in the Hibikinada area of Kitakyushu City. This project was commissioned by the Ministry of the Environment. **Figure 4** shows the outline of the water electrolysis-based EMS demonstration project[9]. This project is a demonstration project in which IHI is working with Kitakyushu Power Co., Ltd., Kitakyushu City, Fukuoka Prefecture, Fukuoka Oxygen Co., Ltd., and ENEOS Corporation. The project includes the first effort in Japan to verify a water electrolysis-based EMS that can control multiple sources of renewable energy, such as solar power, wind power, and waste power (biomass) and the effort to establish a CO_2-free hydrogen supply chain. In this project, IHI is developing and operating an EMS in order to efficiently produce hydrogen with multiple renewable energy sources. In order to produce hydrogen, water electrolyzers must be operated efficiently using surplus power from waste power generation as well as electric power from solar power and wind power, which fluctuate. In this way, we are aiming to reduce hydrogen costs by using electric power that previously was discarded for output control. The hydrogen produced in this project is compressed and filled into cylinder bundles. The cylinder bundles are transported to demand areas, then the hydrogen is used directly from the cylinder bundles or distributed via regional pipelines to be used at hydrogen stations for fuel cell vehicles and forklifts in demonstration tests. In the future, it is expected that in combination with conversion technologies (e.g., methanation, which is mentioned in

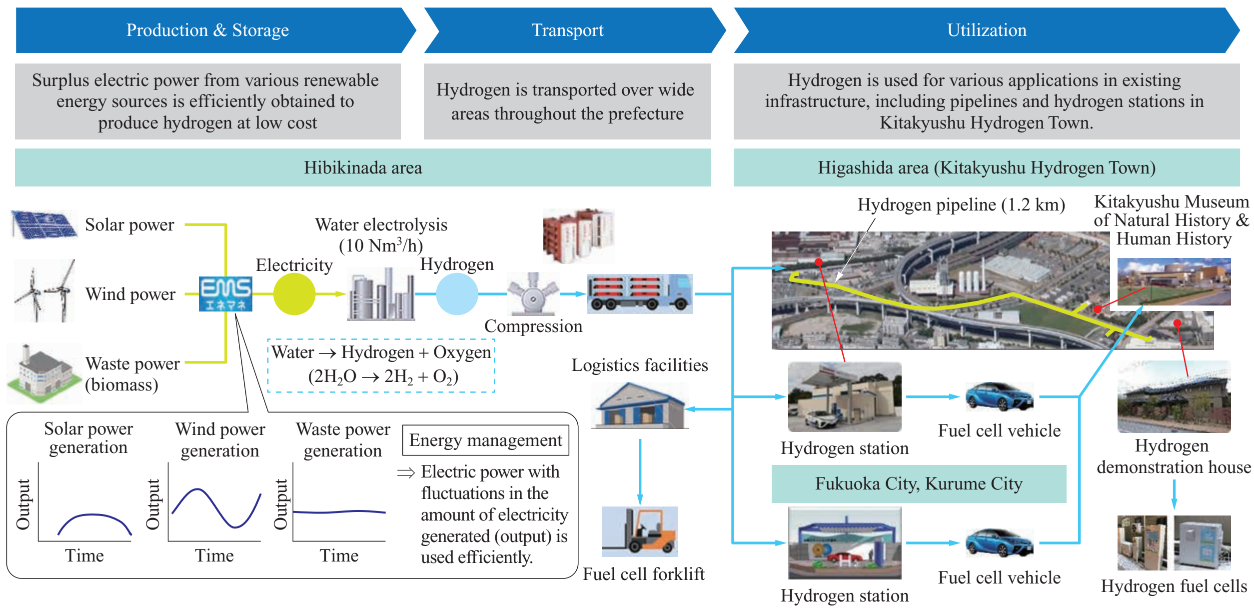

Fig. 4 Outline of demonstration project of water electrolysis-based energy management system[9]

Chapter 2), surplus electric power from renewable energy, which is expected to increase, will be converted to meet various types of demand according to local needs, thereby contributing to the spread of renewable energy.

We are working to expand these efforts globally. For example, we are considering implementation of the Kogan Hydrogen Demonstration Project, which is a joint project with CS Energy, an energy company owned by the state of Queensland in Australia. In the project, hydrogen to be sold is produced with electric power from a solar farm installed adjacent to the Kogan Creek power station, which is owned by CS Energy[10]. **Figure 5** shows the location of the planned site for the Kogan Hydrogen Demonstration Project. Australia has abundant renewable energy, such as solar power, and is expected to become a hub for producing and consuming hydrogen locally as well as a hub for a large-scale ammonia value chain for exporting hydrogen to Japan and other countries in the form of ammonia. We plan to expand this project first in Australia and then globally.

5. Conclusion

Reducing GHG emissions is increasingly required, and IHI is working to develop hydrogen and ammonia value chains, to develop CCU technology, and to develop and demonstrate hydrogen-based distributed energy as described in this paper. Through these efforts, IHI will contribute to reducing GHG emissions in various fields. In particular, we think that spreading distributed energy is required to spread renewable energy. Distributed energy contributes to local production for local consumption and effective use of renewable energy, and enhancement of resilience. Use of hydrogen will help spread and expand the uses of distributed energy.

However, as a challenge to be solved toward the spread of distributed energy, economic feasibility is important. The equipment and running costs of distributed energy are higher than those of conventional large-scale concentrated power generation, and in general, distributed energy is considered to be economically unfeasible without support such as subsidies or added value such as enhancement of resilience. As described in **Section 3.2**, hydrogen production costs remain high, which is a challenge to be solved. In addition to developing distributed energy systems and reducing hydrogen production costs, there is a need to consider converting hydrogen to higher-value-added products and services in order to enhance the value of the entire system and to achieve economic feasibility without subsidies and other support as much as possible. These efforts are essential to realize a sustainable society, and we will work to study and develop the necessary technologies and business models as well as to implement them in society.

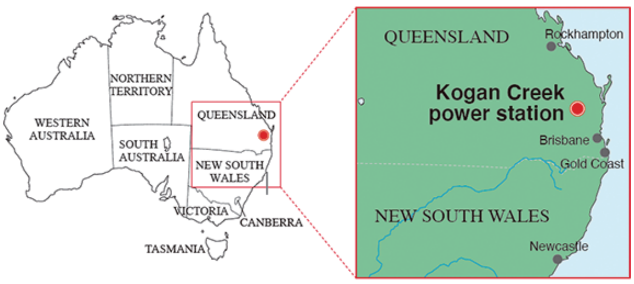

Fig. 5 Location of Kogan Hydrogen Demonstration Project[10]

— Acknowledgments —

The development of a water electrolysis-based energy management system in the Hibikinada area of Kitakyushu City was commissioned by the Ministry of the Environment as part of the demonstration project for low-cost hydrogen models using existing facilities and infrastructures (Project to demonstrate green hydrogen production and supply using local renewable energy in Kitakyushu City). We would like to express our gratitude here.

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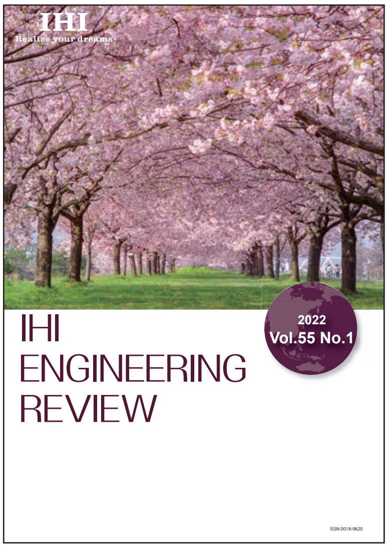

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