Advanced Renewable Energy Technology from Fukushima

National Institute of Advanced Industrial Science and Technology
Fukushima Renewable Energy Institute, AIST
Our Mission

Advanced Research on Renewable Energy

Contribution to Reconstruction

Renewables are valuable domestic energy resources for Japan, and their rapid penetration is expected because they are indispensable for both the prevention of global warming and ensuring sustainability. Cost competitiveness with conventional energy resources, stable supply, and recognition of the regional difference of renewables are key issues for its deployment.

In April 2014, three years after the Great East Japan Earthquake, Fukushima Renewable Energy Institute, AIST (FREA) was established in Koriyama city of Fukushima. As a part of the National Institute of Advanced Industrial Science and Technology (AIST), FREA aims to be a global innovation hub concerning renewables, through creative "Fukushima" technologies. FREA also contributes to revitalize the affected area, by developing new industries and human resources.

We would like to collaborate with you all in this challenge. We appreciate your continued support.

Director-General Masaru Nakaiwa
Gathering of Wisdom and Passion

Three Major Themes and Seven Research Teams

Renewable energies are valuable domestic energy resources for Japan and essential for the prevention of global warming as well as for sustainable development. There are high expectations for mass deployment of renewable energy, but its wide use raises various issues that must be solved, including output fluctuation, high cost, and regional variability. FREA focuses on the following seven research subjects in order to solve these issues and accelerate the large-scale introduction of renewable energy.

**Theme 1**

*System Integration to Facilitate the High Penetration of Renewable Energy*

1. Research and Verification of Advanced Integration Technology for Renewable Energy
2. Production and Utilization Technology for Hydrogen Energy Carrier
3. Hydrogen Energy System and Heat Utilization Technology

**Theme 2**

*Further Cost Reduction and Efficiency Improvement of Renewable Energy*

4. Advanced Technology for Wind Power Generation
5. High-Performance PV Modules Based on Thin Crystalline Silicon Solar Cells

**Theme 3**

*Providing Scientific Information for Penetration of Renewable Energy*

6. Technology for Effective and Sustainable Use of Geothermal Resources
7. Suitability Assessment of Ground-Source Heat Pump System and Its System Optimization Technology

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**Organization**

Fukushima Renewable Energy Institute

AIST

Director-General

Supervisory Innovation Coordinator

Innovation Coordinator

Deputy Director-General

General Affairs Office

Collaboration Affairs Office

DEI Facility Operating Office

Renewable Energy Research Center

Energy Research Team

Hydrogen Energy Research Center Team

Wind Power Team

Photovoltaics Power Team

Geothermal Energy Team

Regional Energy and Hydrogeology Team

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**Renewable Energy Research Initiative**

The Renewable Energy Research Center (RENRC) is a research unit engaged in R&D of renewable energy technologies in FREA. The research center conducts a wide variety of research activities from basic research to system demonstration upon innovative technologies for reduction of power generation cost, large-scale low-cost energy storage and flexible electricity grid and other databases for proper deployment of renewable energy. RENRC consists of seven research teams, which are: Photovoltaics Power Team, Wind Power Team, Hydrogen, Energy Network Team, Hi and Heat Utilization System Team, Geothermal Energy Team, Shallow Geothermal and Hydrogeology Team and Energy Network Team).

As an international innovation hub for renewable energy, RENRC also promotes collaboration with domestic and international research organizations, and contributes to the reconstruction of the disaster areas for Tohoku regions through the development of industrial clustering and human resources.
Energy Network Team
- Research and Verification of Advanced Integration of Renewable Distributed Energy Resources -

When there is high penetration of renewable energy based generation, it is harder to achieve instantaneous demand and supply balance in the network. Advanced utilization of existing power plants and storage systems is imperative to achieve stable energy output. A suitable combination of renewable energy resources for each location is also important, because distributed energy resources (DERs) are highly dependent on local meteorological conditions.

Research Target

The team has been developing a renewable energy network to realize a highly flexible and effective distributed energy system to improve the stability of the existing power grid. This system will allow the consumption of solar energy resources and reduce the cost of energy storage systems. It will allow for a control and support strategy for microgrid control systems. This research aims at developing innovative integration and control technologies which will accommodate a large number of DERs and mitigate their negative impacts. Energy storage systems (ESS), such as hydrogen or batteries, are especially considered in smoothing the power output of PV and Wind generation under varying meteorological conditions.

In particular, we are developing the next generation DER technologies such as solar photovoltaic and wind power, microgrid technology and the integration technology of multiple DER with energy storage for aiming for “safe, secure and fair” energy systems in future. To this end, we are establishing “Solar Resource Application platform (SolRAP)” strategy.

Research Outline

The team is developing performance test methods for DER technology such as DER, ESS, and users’ equipment. In addition, the team is developing a technology for the integrated use of renewable energy in combination with ESS and heat utilization technologies in order to realize a renewable energy network. This will improve the space value and the economic value of renewable energy and promote various introduction plans, such as 100% renewable energy systems. The team is a major research program on the following research and development topics:

- Comprehensive evaluation of a PV generation system predicting the actual amount of power generation of various types of PV modules. This research aims to develop performance verification test procedures and updating environments.
- International standardization: We seek prompt international standardization of the above development results through cooperation with international research institutes and others.

Distributed power sources Energy Resources(DER)

<table>
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<tr>
<th>Energy Demand</th>
<th>Energy Storage (storage batteries and hydrogen)</th>
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<td>Energy Resources(ENERGY)</td>
<td>Utility</td>
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Technical terms handled by the Energy Network Team

Main Research Facilities

- Distributed energy resources (DER) demonstration platform (Figure below)

This platform is used for the development of an energy management system (EMS) and its demonstration through PV systems (consisting of different technologies from four companies), a large power grid simulator (Smart-DEI) system research equipment consisting of a 300kVA AC, DC grid simulator and two sets of 300kW PV simulator. In addition, the platform enables hydrogen production technologies using renewable energy in anticipation of the hydrogen society. This platform is a result of research and development facilities for distributed energy resources (DER), batteries such as electric vehicles and fuel cell technologies linked with forecast technology for solar irradiance and wind velocity (PV demonstration facilities, 20kW class PV systems, EV demonstration facilities, etc.).

*DER: Distributed Energy Resources

Activities and Achievements

1) System integration technology and energy management

The team conducted a performance analysis to verify the economic potential of distributed energy resources, including the introduction of photovoltaic (PV) systems with the three types of twenty (or more) inverters (PV grid-connected system). By implementing DER with ESS, the team conducted a large number of research and development. In the future, the team will promote system research through the demonstration of DER technologies using power smoothing algorithms and electric vehicles.

2) Advanced monitoring of renewable energy resources

The team has developed a renewable energy monitoring and control system to better understand the temporal and spatial variability of power generation when PV and Wind based technologies are integrated. The system is expected to estimate the power generation of PV and wind power in order to forecast the power generation several hours in advance using the same model. The team will continue to improve the system’s accuracy and examine the possibility of its nationwide introduction in the future.

3) Advanced power conditioner (Smart Inverter)

For introduction of large amount of DER, it is needed to have advanced functions to support the stability of grids. We have developed performance test procedures and performance test to test the new functions to be realized with the “Smart Inverter”. We have also developed a simulation tool “SolarGrid” to analyze the advanced functions to support grids.
Research Target

The team has been developing technologies for storing and utilizing a large amount of renewable energy that will help solve several energy issues facing Japan. We have been developing technologies for converting renewable electricity into hydrogen or hydrogen energy carriers, which is utilized by generating electricity, heat, and hydrogen. These technologies are useful for stabilizing the power grid even when massive amounts of renewable energy are introduced in the future. The result will be the efficient use of a much greater amount of renewable energy regardless of the location and season.

Research Outline

The team has been developing a set of hydrogen technologies using electric power generated by fluctuating renewable energy hydrogen production by water electrolysise, chemical conversion in a hydrogen energy carrier, and utilization of hydrogen. Basic technologies such as production of hydrogen energy carriers and the catalysts, and hydrogen engines are applied to large-scale demonstration equipment, and the knowledge gained through the experiments is applied to technological development. These technologies include high-efficient production of hydrogen energy carriers (e.g., organic chemical hydride, ammonia, formic acid). We are developing high-efficiency technologies for catalytic production of hydrogen.

Main Research Facilities

Hydrogenation/Dehydrogenation Reaction Apparatus

Catalytic hydrogenation and dehydrogenation reactions are analyzed by in-situ gas chromatography. Simulated fluctuating hydrogen demand from renewable energy can also be applied. Hydrogen flow rate: 1600 mL/min, volume and WHF flow rate: 18 g/min.

Advanced Cogeneration Engine

Excessive experimental and multi-fuel engine combustion technology with hydrogen, diesel fuel, etc., using a hydrogen direct injection engine (displacement: 3.2L).

Storage

One of the biggest demonstration systems of MCH production and utilization in the world. This system integrates the alkaline water electrolysise, catalytic hydrogenation reactor, large storage tanks, and cogeneration engine with the catalytic dehydrogenation reactor.

Activities and Achievements

1) Evaluation of catalytic performance of organic chemical hydride (Fig. 1)

Products and by-products have been quantitatively measured by using a catalyst evaluation apparatus with an on-line GC. Currently, developing a design guideline for the production process of organic chemical hydrides and collecting data for standardization in the future market. Recently, obtained fundamental data for the dynamic optimization of hydrogenation and dehydrogenation processes.

2) Unified demonstration system of hydrogen energy carrier production/utilization

One of the world’s largest demonstration systems for hydrogen energy carrier production and utilization. The alkaline water electrolysise in this system successfully converted 30 MWh of electricity to hydrogen (equivalent to 300 days of ordinary home electricity consumption), and a new simulator capable of predicting the performance of the electrolysise has been constructed. In addition, this demonstration system has been incorporated into the FREA’s energy network and we will propose a strategy for electricity storage and utilization.

3) Advanced cogeneration engine using H2 from MCH (Fig. 2)

Development is underway on a next-generation cogeneration engine with a dehydrogenation catalytic reactor of MCH that can recover the exhaust heat from engines. The world’s best hydrogen generation from MCH is realized by enhancing the recovery of heat such as the exhaust gas temperature of engine exhaust in terms of engine combustion technology for dual fuel hydrogen and diesel; high-thermal efficiency exceeding 40% and high exhaust temperature were achieved. While the exhaust temperature usually drops at high efficiency, the MCH could be decomposed by retaining the high-exhaust temperature. In addition, efficient and clean combustion technologies are improved by maintaining a higher exhaust temperature for dehydrogenation of MCH.

4) Development of internal combustion engine firing ammonia (Fig. 3)

This team is collaborating with Tohoku University on technology research for the direct combustion of ammonia. Work has been done on a micro gas turbine (rated power: 30 kW) and 41 kW power generation was successfully achieved by burning methanol–ammonia gas or 100% ammonia. These are world-leading research results. In terms of nitrogen oxide (NOx) emission, the gas turbine fueled with ammonia emits less than 25 ppm of NOx by using NOx removal equipment. This emission level meets the standard of the Ministry for the Environment of Japan.

This research and development is being conducted under the Cross-Ministerial Strategic Innovation Promotion Program (SIP) “Energy Carrier” of the Cabinet Office (Management Corporation JST).

Specifications

Hydrogen generation capability by alkaline water electrolysise: 14 MWh Hydrogen generation (MCH production capacity) MCH storage capacity: 20 L (corresponds to power generation: about 15 MW) Cogeneration output (electricity and heat): power 60 kW and heat 35 kW

Fig. 1: Hydrogenation and dehydrogenation cycle of MCH

Fig. 2: Thermal efficiency and exhaust gas temperature as a function of the hydrogen ratio of the next-generation cogeneration engine

Fig. 3: Ammonia gas turbine
Research Target

This team is developing an energy system that utilizes hydrogen as well as heat, and is capable of storing a large amount of energy in the long term. This has been an issue that cannot be solved by power systems or existing energy storage technology, in order to introduce large amounts of renewable energy. With the surplus power from photovoltaic systems that will be increasingly introduced in the future, we will develop high-efficiency, low-cost hydrogen production technology. In order to reduce emissions from buildings, which account for 40% of Japan's CO2 emissions, we will utilize CO2-free hydrogen to develop a hydrogen storage technology that can be used in urban areas. We are developing an energy system that makes full use of hydrogen and thermal energy in accordance with demand for heat as well as electricity. Further, in anticipation of the widespread use of fuel cells as a way of utilizing hydrogen, we are also working on safe hydrogen boosting and refining technology.

Research Outline

The team continues to develop high-efficiency hydrogen production technology by utilizing surplus power from solar power generation, which is expected to be introduced and used in large quantities in the future. We will aim to achieve both system utilization and hydrogen production, which are expected to come when the Feed-in Tariff ends. Specifically, we are aiming for high efficiency with proprietary technology that directs DC power from photovoltaic systems to the water electrolyzer by controlling the number of electrolysis cells.

As a technology for storing hydrogen, the team is developing hydrogen storage techniques that use solid hydrogen. In order to preserve the use of hydrogen in urban areas, we are developing an inexpensive, safe, and largescale hydrogen storage method that is not subject to the High Pressure Gas Safety Act and Fire Service Act, by using a metal hydride that has a pressure of 1 MPa or less and does not ignite.

- The team is developing technology to meet the demand for electricity and heat with the use of energy systems that utilize hydrogen, aiming at zero emissions buildings. Here, we are demonstrating this technology using the newly developed hydrogen storage systems.
- The team will develop new hydrogen compression technology and refining technology for wider utilization of hydrogen.
- In order to further improve the functionality of these technologies, the team will develop and demonstrate thermal power generation and thermal storage technology for effectively using solar heat and unused waste heat.

Water electricizer with directly connected solar cells equipped with capacitor smoothing device

Solar Power Generation Direct Electrolyzer

A 20 kW solar cells connected directly to the water electricizer. The water electricizer is capable of switching the number of electrolysis cells and following the maximum power point of the solar cell. We are also attempting to smooth the fluctuation of solar radiation by connecting lithium-ion capacitors (LiC).

Field Emission Scanning Electron Microscope (FE-SEM)

Various Analyzers

This team has the following various analyzers: examples field emission scanning microscopy, X-ray diffraction meter, BET characteristic evaluator, hydrogen-permeable membrane evaluator, surface tensiometer, thermal conductivity meter, thermal analysis device (TGA/DTA/DCS).

Activities and Achievements

1) Water Electrolysis Degradation Prevention Technology

The team has succeeded in converting approximately 15% of solar energy into hydrogen-energy using 20 kW solar cell and a 5 Nm³/hour water electricizer. Electrolytic current that varies depending on the weather can be smoothed using lithium-ion capacitors, which makes it possible for the electricizers to have a longer lifespan.

2) Safe Hydrogen Storage Technology (non-burnable metal hydride)

The team has developed an inexpensive metal hydride that does not use rare-earth elements. As shown in the photograph, even after repeated hydrogen absorption/desorption is performed, it does not ignite. It is therefore an alloy that is not designated as a hazardous material under the Fire Service Act (certified).
Research Target

The team aims to establish elemental technologies for a high-performance wind turbine and its control strategies, and wind assessment technologies for the site selection and operation of wind farms, in cooperation with the domestic wind power industry. These technologies will help reduce the cost of wind power generation, stimulate the domestic market, and improve the international competitiveness of the wind power industry in Japan.

The team has set the following goals:

1. Improvement of the power output by 5% or more and the lifetime of wind turbines by 60-100% or more by developing elemental technologies for improving the performance of wind turbines and entire wind farms,
2. Advancement of assessment technologies for accurate wind measurements with errors of less than ±5% in annualized speed and the reduction of assessment costs by 20-30%.

Research Outline

1. Elemental technology for a high-performance wind turbine
   The team has demonstrated a prototype of a nacelle-mounted LEAR as a new technology for measuring the wind speed and direction upwind of the turbine rotor plane. LEAR measurement flow and turbine feed-forward control can be combined to optimize the turbine cyclic blade and rotor speed to alleviate fatigue effects on the tower, gear and blades coming from wind gusts and wind shear during daily operation. By adopting the fast feed-forward strategy, the lifetime of the wind turbine can be prolonged and the power performance is improved.

2. Offshore wind resource assessment using a numerical meteorological model and satellite remote sensing
   To select a site and design a wind farm, the wind speed and direction are the key factors. Wind measurement using a meteorological mast is very expensive, especially at an offshore site. To accurately measure the wind speed and direction, new technologies using a numerical meteorological model and satellite remote sensing have been developed. These technologies are also expected to help reduce the measurement costs.

Activities and Achievements

1. Field demonstration results of the nacelle-mounted LEAR (Fig. 1)
   The team succeeded in remotely measuring the wind speed distribution on the upstream side of a wind turbine using a high-performance nacelle-mounted LEAR. The team found that the wind power could be increased by up to about 6% by reducing the appearance frequency of yaw misalignment larger than 3°10' based on the information about the wind direction in front of the wind turbine obtained with the nacelle-mounted LEAR.

2. Advanced assessment technique (Numerical meteorological model) (Fig. 2)
   The team developed a simulation environment for improving the spatial resolution of the numerical meteorological model by using the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data obtained from the Ministry of Economy, Trade, and Industry. The team also developed the high-resolution sea surface temperature dataset Modis-based Sea Surface Temperature (MODIS SST) (Imada et al., 2005), which significantly improves the reproducibility of atmospheric stability near the sea surface.

3. Advanced assessment technology (Satellite remote sensing) (Fig. 3)
   The team developed a method for retrieving sea surface wind speed by using a satellite-borne synthetic aperture radar (SAR) in consideration of atmospheric stability. Moreover, it was clarified that the relationship between fetch and retrieval errors during offshore winds is remarkably different from that during onshore winds due to the land effect.
Capturing Solar Energy

Research Target

The team addresses the following subjects to develop technologies for producing low-cost, highly efficient, and reliable modules (target conversion efficiency: 22%):
- Silicon ingot slicing technology with high accuracy and reproducibility (thin wafer)
- High-efficiency cell fabrication technique using thin Si wafers (PERC cell back contact cell, etc.)
- Technologies for improving the efficiency and reliability of PV modules (development of new materials, structures, etc.)

The team is also conducting research on “smart stack technology” to develop next-generation high-efficiency solar cells (conversion efficiency higher than 30%). Technologies to achieve the power generation cost target of 14 yen/kWh in 2025 and 7 yen/kWh by 2030 will be developed.

Research Outline

Although crystalline silicon (c-Si) technology has the dominant share in the PV market, it must be reduced significantly in order to accelerate the deployment of PV systems.

The team conducts comprehensive research using a system approach from ingot slicing to module fabrication and testing.

- Thin wafer fabrication technology
  The team is developing a slicing technology for thinner wafers with a thickness of about 0.1 mm from the present thickness of 0.18 mm to 0.04-0.05 mm.
  The team is also investigating the relationship between cracks and wafer strength to develop thin and tough wafers and to improve the yield during slicing processes such as wafer cleaning.

- Development of new cell fabrication techniques
  New cell production processes using an ion implantation technique have been developed in addition to the conventional thermal diffusion process. The effective use of ion implantation can reduce the number of cell processes during back-contact cell fabrication.

- Improvement in module reliability and development of a new evaluation method
  A new visualization method of internal field of solar cells by assessing the raster emission has been developed using a Laser Terahertz Emission Microscope (LTEM) in collaboration with SCREEN Holdings Co., Ltd. This method optically visualizes junction layers of interdigitated back contact (IBC) solar cells.

Major Achievements

- Next-generation multi-junction solar cell “smart stack technology”
  The “smart stack technology” using metal nanoparticle arrays has been developed, making the interconnection of various solar cells with different materials and bandgaps possible for the first time. This provides flexibility in material choice and device design because the mismatch in lattice constants, thermal expansion coefficients, etc. can be disregarded with this technique.
  A GaAs/InP-based three-junction solar cell has achieved conversion efficiency as high as 31.6%, and a GaAs/Ge-based three-junction solar cell has achieved conversion efficiency as high as 24.2%. Joint research with the Research Center for Photovoltaics at AIT-Tokuba Center. The team is developing crystalline silicon based smart stack cells that go beyond the theoretical efficiency limit of single-junction crystalline silicon solar cells (29%). A demonstration GaAs/Si three-junction cell with conversion efficiency of 25.1% has been successfully fabricated.

- Main Research Facilities
  - Electrode firing furnace: Furnace for forming contacts between the electrodes and the diffusion layer as well as Al-BSF layers.
  - Spin coating apparatus: A process that enables a single side of the wafer to be coated with a protective film.
  - Sublimation equipment: Equipment that enables wafer-based phosphorus or boron ions in the wafer to diffuse. The diffusion profile can be precisely controlled.
Research Target

The team is conducting research and development for the sustainable use of geothermal energy in Japan. The team also conducts basic studies in geosciences to improve the scientific understanding of geothermal systems. Since the area underground is insensible and the properties of geothermal resources depend on the specific area, it is very important to acquire actual data in the field for conducting geothermal studies. The team therefore conducts field experiments, monitoring, equipment testing, etc. at many field sites mainly in the Tokachi region. The team mainly aims to accomplish the following goals:

- Understanding and visualizing the phenomenon that occurs in the reservoir by developing a sensing system for monitoring geothermal energy using microelectromechanical systems (MEMS), optical fibers, etc. and by developing advanced analysis technologies such as transient multicomponent signal processing and integrated interpretation.
- Compiling huge amounts of geothermal resource information possessed by ABT into an advanced database, presenting optimal development methods, and achieving consistent with hot springs by developing a geothermal energy simulator.
- Developing an optimal reservoir creation and control technology using hydraulic stimulation and fluid injection, through laboratory tests and numerical simulations. This allows us to achieve a universal development tool.

Research Outline

The team is conducting various projects commissioned by the national government, private companies, and others to establish the proper utilization of geothermal energy in Japan. The team also conducts basic studies in geosciences to improve the scientific understanding of geothermal systems. Since the area underground is insensible and the properties of geothermal resources depend on the specific area, it is very important to acquire actual data in the field for conducting geothermal studies. The team therefore conducts field experiments, monitoring, equipment testing, etc. at many field sites mainly in the Tokachi region. The team mainly aims to accomplish the following goals:

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- Developing an optimal reservoir creation and control technology using hydraulic stimulation and fluid injection, through laboratory tests and numerical simulations. This allows us to achieve a universal development tool.

In order to prevent a decrease in steam production and to recover production, seismic and relaxation tests have been conducted at the Yanaiwakihiguma Geothermal Power Plant in Fukushima Prefecture since FY2015. In this area, the Geothermal Energy Team installed a precision microearthquake remote monitoring network using a three-component downhole accelerometer for a geothermal well and other equipment, and operations were commenced. This enables real-time monitoring of microearthquake activity and advanced integrated analysis in FREA, and our plan is to contribute to production recovery through appropriate water injection.

Activities and Achievements

1) Development of simulator for water injection to a geothermal well

In some cases, the capacity of a geothermal reservoir is improved by injecting water into the reservoir through a geothermal well. The Geothermal Energy Team collaborated with US and European researchers and developed a simulator for investigating the response to a crack for water injection. As a result of conducting a demonstration test on a well with reduced capacity in a geothermal field, the team boosted capacity as predicted by the simulation and succeeded in increasing the power generation (to about 1.1 MW).

2) Development of a remote and continuous system for monitoring a hot spring’s quality

The team began developing a system for measuring a hot spring’s qualities, including the temperature, flow rate, electric conductivity, etc. producing a prototype to scientifically explain the relationship between geothermal power generation and hot springs. This system enables real-time measurements and continuously transmits the obtained data in a stable manner through the internet. The field performance evaluations by laboratory experiments and field demonstration tests for practical application will continue to the end of FY2017.
Energy Saving using Underground

Research Target

The GSHP system is highly efficient and energy-saving compared to normal air conditioners (al-source heat pump system). The team has been promoting the GSHP system by enhancing its performance and lowering its cost based on geological information.

There are two types of GSHP systems: a closed-loop system exchanges heat by circulating water in pipes buried underground, while an open-loop system pumps up groundwater to exchange heat at the ground surface. In Japan, since the existence of groundwater and its flow rate largely affects the heat exchange rate in both cases, it is important to investigate the groundwater burden and flow rate. The Japanese approach to research on GSHP considering the groundwater system may be applicable and beneficial for Southeast Asian countries. Therefore, we are engaged in the following research targets to develop GSHP systems suitable for the hydrogeological characteristics of a site:

- GSHP suitability mapping based on field data collection and schematic model construction
- Conceptual design and operation technology of a GSHP system
- Expansion of GSHP studies in Southeast Asia and other regions

GSHP: Coefficient of performance

Research Outline

To use a GSHP system, it is important to understand the subsurface hydrogeological conditions of the site. Therefore, we conduct geological surveys by boring, groundwater temperature surveys by depth, regional heat transport simulations with advection effects of groundwater flow, etc. to investigate the suitability of a GSHP system to the subsurface environment of the area.

The team also conducts studies on the development of GSHP systems suitable for different subsurface conditions. At a GSHP demonstration test site of FREA, the team conducts experiments using two types of heat exchangers: shallow (horizontal) and deep (vertical). The identical system is installed at the Geological Museum of AOMI in Tsuchiura City, Ibaraki Prefecture. To investigate the differences in heat exchange performance and optimize heat exchange systems in each area having different hydrogeological settings.

The team is mainly engaged in the following research and development themes:

- Research on GSHP suitability assessment
- Technology development for GSHP systems optimization

Main Research Facilities

Activities and Achievements

1) Analysis of the hydrogeological structure of the Abur Basin

Through joint research with Fukushima University, the team conducted an analysis of the geological structures of the Quaternary layer and the hydraulic structure (incuding subsurface temperature distribution) in the Abur Basin, Fukushima Prefecture, to reconstruct the basic design for assessing the suitability of GSHP systems.

2) Suitability assessment for GSHP system installation in Abur Basin

The team constructed a three-dimensional groundwater flow and heat transport model based on the geology data obtained from the analysis of geological structure of the Abur Basin (Fig. 1). Using the model results, the team then conducted a suitability assessment for the closed-loop system and prepared a distribution map of estimated heat exchange rates (Fig. 2). This kind of suitability map that illustrates regional variation of heat exchange rates is essential to select the suitable location for the optimum design of GSHP systems.

3) Performance evaluation of a closed-loop GSHP air-conditioning system using an artisan well

The team constructed a closed-loop GSHP system using an artisan well in a joint project research with Kansai Electric Power Co. Ltd., through the "Program for Promoting Technologies Invented by Industry in Disaster Areas in Tokushima". The team built a system to control the natural flow using the well temperature, COP higher than 5.5 in the cooling operation and COP higher than 4.3 in the heating operation were observed; however, this depends on the operating conditions.
AIST's research base and priority research theme

Facilities

1. Energy Control Building
   Conducting studies on a renewable energy network through the integration of large-scale PV and wind power systems with power storage using hydrogen and batteries.
   - Characteristics:
     - Grid simulator (50 kW)
     - PV simulator (100 kW)
     - PC-Bus (100 kW)
     - BESS (100 kW)
     - PV power conditioning system (three types, one unit for each type)
     - Solar simulator for PV modules (simulated sunlight source)
     - MT-1 test device for PV modules
     - EMS (Energy Management System)
   - Area: 10,000 m²

2. Hydrogen Energy Carrier Demonstration Building
   One of the world's largest MCH production and utilization demonstration systems with an alkaline water electrolyzer, hydrogen generation catalytic reactor, large storage tank, and dehydrogenation catalytic reactor with integrated cogeneration engine is operated to demonstrate a hydrogen energy carrier production and utilization integration system.
   - Characteristics:
     - Hydrogen generation capacity by alkaline water electrolysis: 34.3 km³/yr
     - Hydrogen generation capacity of MCH production system: 80 km³/yr
     - MCH storage capacity: 24 km³ (power generation conversion about 16 MWM)
     - Hydrogen cogeneration output (power and heat) power 50 kW and heat 35 kW

3. Pure Hydrogen Experiment Building
   Conducting research on hydrogen energy storage systems and thermal energy storage systems.
   - Characteristics:
     - Membrane exchange type water electrolyzer (with Fuel Cell Operation)
     - Solid Thermal System
     - Methane hydrogen storage system
     - Quick charger for electric vehicles
     - Charge and discharge equipment for electric vehicles (2 lbf/25) km
     - High-pressure hydrogen experimental facility
   - Area: 10,000 m²

4. Photovoltaic Power System Demonstration Field
   - Characteristics:
     - Rated output: 100 kW
     - Number of modules: 11 types
     - Power conditioner: PV generation (three types, 22 units)
     - Area: 10,000 m²

5. Wind Power Generation System
   Conducting verification of the JAEA-Bliss wind turbine design criteria and a demonstration study on advanced wind turbine control technology. A wind-tunnel simulated by CFD can be used to evaluate and explore the wind turbine noise using a sound-sensitive surveying device to elucidate the noise properties and also conduct studies on noise reduction.
   - Characteristics:
     - Rated power output: 0.3 MW
     - Power conditioner: 1.5 MW
     - Low noise (30 km/h)
     - Max wind speed: 11.5 m/s
     - Max wind speed: 25 m/s
     - Max wind speed: 35 m/s
     - Max wind speed: 45 m/s

6. Annular Direct Combustion Gas Turbine Demonstration Facility
   Conducting research and development on the technology for gas turbine power generation that could burn and use hydrogen carrier ammonia fuel.
   - Characteristics:
     - Low NOx gas turbine power generator (dual output: 50 kW (bus power operation))
     - Low NOx gas turbine power generator (dual output: 100 kW (bus power operation))
     - Inert gas, methane, gas, nitrogen, or steam is used as fuel
     - The test rig is used to test gas turbine power generation of 47 kW by burning methanol-ammonia mixed gas. Maximum 40 kW of power was realized, generated by burning only ammonia (80% ammonia as fuel: 30% methane, 20% nitrogen)
     - The concentration of nitrogen oxide emissions discharged from the NOx removal equipment satisfied the environmental criteria.
Facilities

Thin-Crystalline Silicon Solar Cells R&D Foundry

An integrated manufacturing line of thin-crystalline silicon solar cells was provided in an annex building of FREA to develop the technology for mass-producing solar-cell modules with high efficiency, low cost, and high reliability. In this line, cells can be produced with conversion efficiency equal to or greater than that of mass-produced goods of manufacturers.

1. Silicon Ingot Slicing (Wafering)
2. Surface Texture Formation
3. PV Junction Formation
4. Antireflection Film Deposition
5. Electrode Printing and Firing
6. Photovoltaic Module Fabrication and Reliability

MultiWire Saw
Surface Texture Formation Machine
Thermal Diffusion Apparatus
Ion Implantation Machine
PE-CVD Machine
Electrode Printing and Firing Machine
Vacuum Laminator
Reliability Test Machines

Ground-Source Heat Pump System Demonstration Area

Overview of Ground-Source Heat Pump System Demonstration Area

Installation state of underground heat exchanger

At the demonstration test site for the geothermal heat utilization system at FREA, two GHP systems are installed, one using a single-type and a double-type heat exchanger installed at a depth of 1-2 m under the ground and the other using a single-type (Borehole type) heat exchanger installed at a depth of about 40 m. Based on a comparison of these systems, the team is developing a technology for optimizing an operating method combining both systems.

Facilities

Smart System Research Facility

Cutting-Edge Research, Development and Evaluation for Large DER Systems

The Smart System Research Facility provides one of the world's largest testing and research platforms. This cutting-edge research facility is capable of supplying up to 5.0 MVA by grid simulator to test large power electronics devices. This national facility enables integrated megawatt-scale research and development of the components, systems and strategies required for safe and efficient DER penetration. The facility provides globally consistent test results and drive international standardization through international cooperation. Furthermore, evaluation of products with respect to international regulations is performed. The main facility has the following four test capabilities.

Grid Connection Testing

Japan's largest grid connection test facility. Accepts a 20MW-cale container and is capable of supplying 5.0 MVA grid conditions using 3.5 MVA DC simulator with an emulated power distribution line

Safety and Reliability Testing

A large-scale environment test chamber to conduct reliability and performance tests such as temperature and humidity cycle tests. This facility can create different climate conditions such as high-temperature and high-humidity areas, and very cold areas. Temperature range: -40°C to +80°C, humidity range: 30-90% RH

Electromagnetic Environment Compatibility (EMC) Testing

Japan's largest anechoic chamber with power supply. This facility is used in EMC tests for power electronics devices and ICT devices, which are indispensable for smart grid systems.

System Performance Testing

Integrated DER system testing facility. This facility provides the testing environment for the Energy Management System (EMS) using advanced smart technologies such as the combination system of PV and ES with smart inverter, automated control system of ES and various other performance tests for integrated systems.
Power to Alliance

Outreach Activities
FREA promotes collaboration in various ways. The figures show the data for FY2015 excluding pie chart.

Joint Research
FREA conducts joint research from basic to applied research.
- With Universities and Technical Colleges: 28
- With Companies: 73
- Others: 9

Total: 110
FY2017

Technical Advice
Requests for technical advice or face-to-face meetings are received by email, telephone, and regular mail.
FY2017: Total: 46

Technical Consulting
We provide consultancy services from evaluation of seeds to commercialization of technology based on the stage of development.

Contract Research
We accept contract research from companies by utilizing our research capability for commercialization of research results.
FY2017: Total: 23

Transfer of IP
ABIT promotes the commercialization of research outcomes by filing its IP (patents, knowhow, and programs as research assets) and is willing to license such assets to those who wish to utilize them.

Laboratory Tour
Number of Visitors
- Citizens: 741
- Students: 1,266
- Researchers: 4,124
- Total: 4,596 (FY2017)

Activities for Open Innovation
Promotion of International Collaboration
The Global Alliance for Solar Energy Research Institutes (GARES, Fraunhofer ISE, and NREL) convened a worldwide gathering of experts to discuss the future role of photovoltaics in energy prosperity and climate change mitigation.

Outreach of Research Results
FREA holds symposia for reporting research results and publicizes in various events and exhibitions to distribute information about the recovery of Fukushima to the public.

Collaboration with Local Industries
Through collaboration with local municipalities (FRA) participates in the activities of the Fukushima Renewable Energy Valley Promotion Research Society and exhibits at events promoting local industries.

Open Laboratory
This is an annual event for the public. We guide the participants through our laboratory to give them a sense of advanced technologies. Also displayed are samples and prototypes developed by local high school students, etc.
Contribution to Reconstruction

Program for Promoting Technologies Invented by Industry in Disaster Areas in Tohoku

- New Support Program for Development and Industrialization of Renewable-Energy-Related Technologies of Companies in Disaster Areas, FY 2018
- In order to contribute to industrial clustering and revitalization, FREA has been providing technical support for renewable-energy-related technologies of companies located in the disaster areas (Fukushima, Miyagi, Iwate Prefectures) by utilizing knowledge, experience and research facilities of FREA since FY2013. In addition to this effort, from FY 2018, FREA has just started new support program. In this program, FREA emphasizes to support consortium of companies in the disaster areas on the basis of technology achievement in the former program.

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In FY 2013-2017
Number of Research Subjects Adopted in the Program for Strengthening R&D Function of FREA

Examples of Commercialization

- High-performance crosslinking coagent for EVA encapsulants in PV modules by Nippon Kasei Chemical Co., Ltd.
- PV module bypass diode checker by Nippon Kernel System Co., Ltd.
- PV array string monitoring and diagnosis system by Asahi Denshi Co., Ltd.
- Temperature stratified hot water storage by Kameyama Iron Factory Inc.

Industrial Human Resources Development Projects

- FREA has been providing opportunities for human resource development since FY2014 in renewable energy field for local university students through collaborative research and development activities.

Visit to binary cycle power plant at hot spring

Presentation by RA at Exhibitions

Achievement

- Technical staff
- Technical trainee
- Research assistant
- Postdoctoral researcher

- Research Assistant Program
- This program offers opportunities for students as Research Assistants (RA).
- This helps students concentrate on their studies and research by partly reducing their financial burden.

- Technical Training
- This program offers opportunities for students as technology trainees to learn about cutting-edge testing and analysis technology by using our modern research facilities.
Access

By car
About 5 km from Tohoku Expressway "Koriya IC" (about 10 minutes).
Proceed in the direction of Inawashiro (right) at the exit of the interchange.

By plane
Take a limousine bus at Fukushima Airport for Koriyama Station. (Takes about 40 minutes and costs 1,100 yen.)

From Koriyama Station
1) Take a taxi at Koriyama Station. (Takes about 25 minutes and costs about 4,000 yen.)
2) Take a train (JR Ban'etsu West Line) at Koriyama Station, get off at Kikuta Station, then take a taxi (takes about 10 minutes and costs about 1,200 yen.)
3) Take a bus (Fukushima-Kotsu Bus) at Koriyama Station: bus station No. 8 for Koriyama Western Industrial Complex. (Takes about 40 minutes and costs 710 yen. Please note that the number of bus services is limited.)

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