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

FREA
FUKUSHIMA RENEWABLE ENERGY INSTITUTE, AIST

Renewables are valuable domestic energy resources for Japan, and its rapid penetration is expected because they are indispensable for both the prevention of global warming and maintaining sustainability. Cost competitiveness with conventional energy resources, stable supply, and recognition of the different regional situation of renewables, are key issues to accelerate for the use of renewable.

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 Six Research Teams

Renewable energy is a valuable domestic energy resource for Japan and is essential for the prevention of global warming as well as for sustainable development.
There are high expectations for massive use of renewable energy, but its widespread introduction raises various issues to be solved, including output fluctuation, high cost and regional variation.
FREA focuses on six research subjects under three themes in order to solve these issues and accelerate the large-scale utilization 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

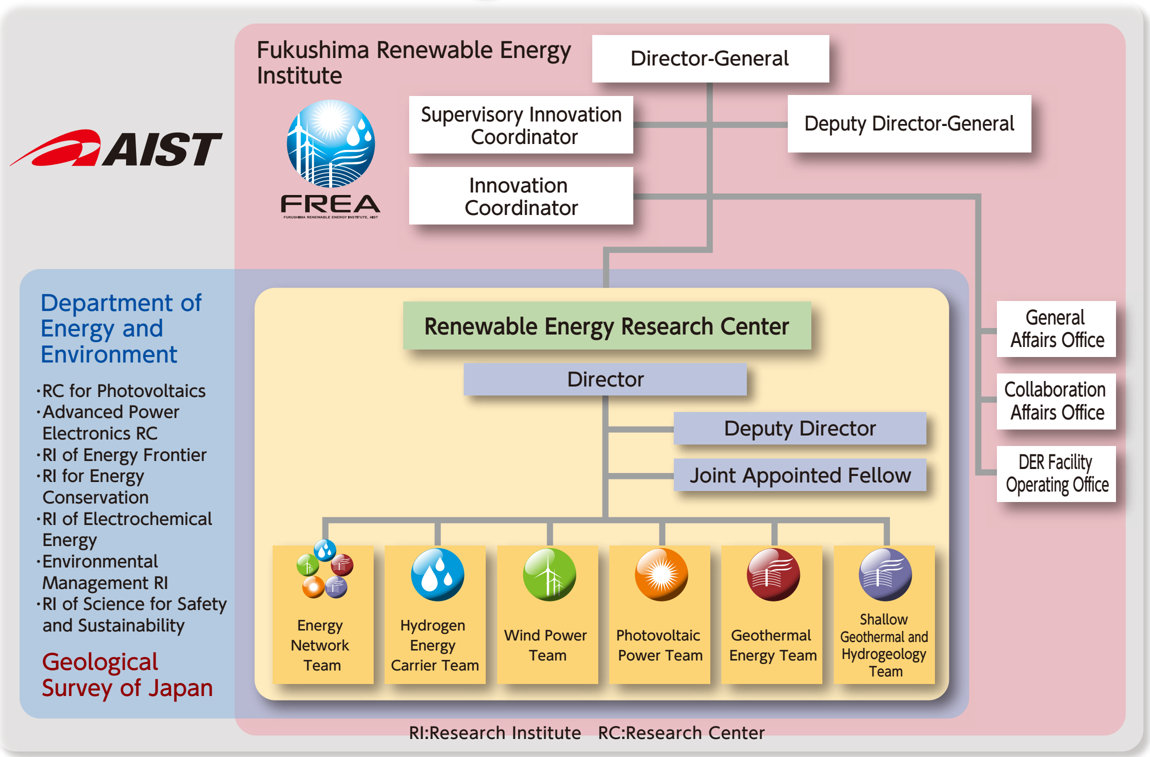
Theme 2 Further Cost Reduction and Efficiency Improvement of Renewable Energy

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

Theme 3 Database Development for Proper Deployment of Renewable Energy

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

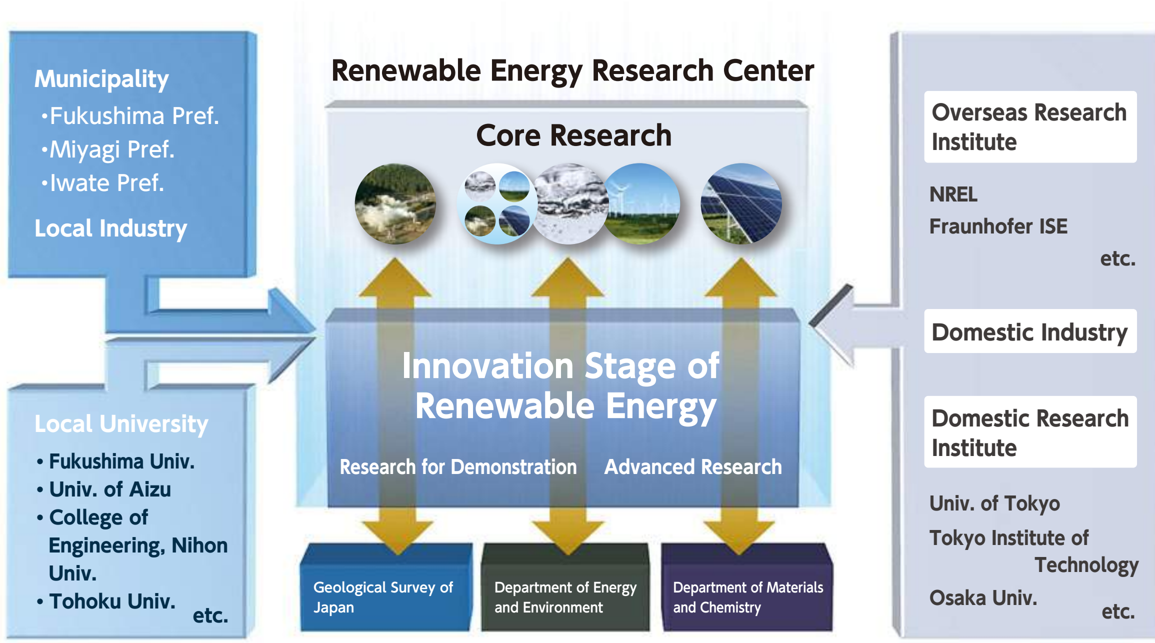
Organization



Director,
Renewable Energy Research Center
Hirohide Furutani

The Renewable Energy Research Center (RENRC) is a research unit engaged in R&D of renewable energy technologies in FREA. In order to accelerate the mass deployment of renewable energy, 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 upon database for proper deployment of renewable energy. RENRC consists of six research teams (Photovoltaic Power Team, Wind Power Team, Hydrogen Energy Carrier 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 contribute to the reconstruction of the disaster areas for Tohoku regions through the development of industrial clustering and human resources.

Renewable Energy Research Initiative



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Energy Network Team

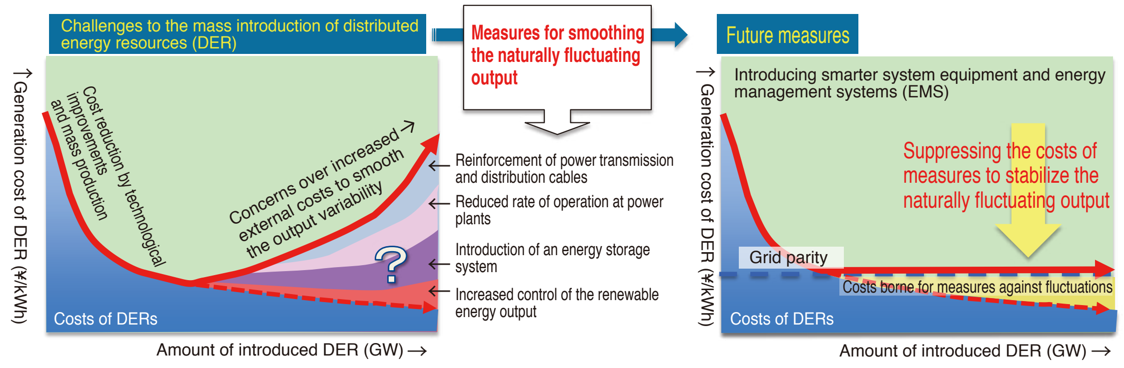
– Research and Verification of Advanced Integration of Renewable Distributed Energy Resources –

In order to provide stable energy in the case of widespread use of variable renewable energy resources, it is essential to adjust the simultaneous balance of power supply and demand by using existing power plants and energy storage systems. 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 reasonably and effectively introduce renewable energy into the mature legacy power grid system. This will reduce the consumption of finite energy resources (fossil fuels, etc.) and reduce CO_2 emissions. We focus on advanced control and grid support technology for a smart inverter (PCS). This research topic aims to develop integration technology for both stabilizing and maximizing multiple DERs, especially PV and wind, by using energy-storage systems (ESS) such as hydrogen and batteries in the case of naturally fluctuating electricity conditions due to the metrological environment. The team proposes a new energy supply system based on a renewable energy network with renewables and DERs. It will be built by combining utility-scale PV generation and ESS including the hydrogen system. This approach will create a new energy supply model from the perspective of electricity users, through flexible demonstration facilities and our test platform.

- Realization of smart distributed energy resources (DERs) through the use of advanced power equipment such as the smart inverter or PCS.
- Optimization of system integration through the use of information communications technologies (ICTs) and meteorological data.
- Hydrogen production from renewable energy and development of related technology.



Solutions for widespread use of renewable energy and cost-effective grid stabilization technology

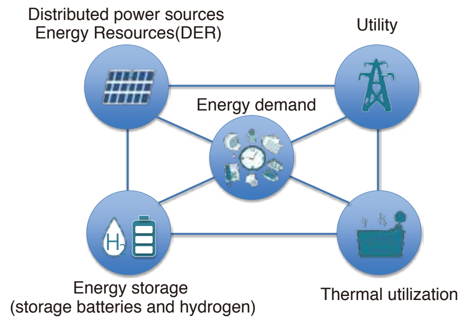
Research Outline

The team is developing a performance test method for elemental technologies such as DER, ESS, and users' equipment in addition to a technology for the integrated use of renewal energy in combination with ESS and heat utilization technologies in order to realize a renewable energy network.

This will improve the power supply value and the economic value of renewable energy and promote various introduction plans such as 100% renewable energy use.

The team is mainly working on the following research and development topics:

- Comprehensive evaluation of a PV generation system: predicting the annual amount of power generation of various types of PV modules, conducting PV inverter performance tests and field failure diagnosis of a utility-scale PV system, etc.
- Hydrogen production and storage technology using renewable energy: Technology for direct electrolysis from a PV system (solid polymer-type water electrolyzer with a fuel-battery function), hydrogen storage using metal hydrides, compression, hydrogen separation membranes, solar heat utilization and heat storage technologies, etc.
- Grid support and smart technology for DER: We provide a smart test platform for energy management systems (EMS) as a user facility and keep developing 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, etc.



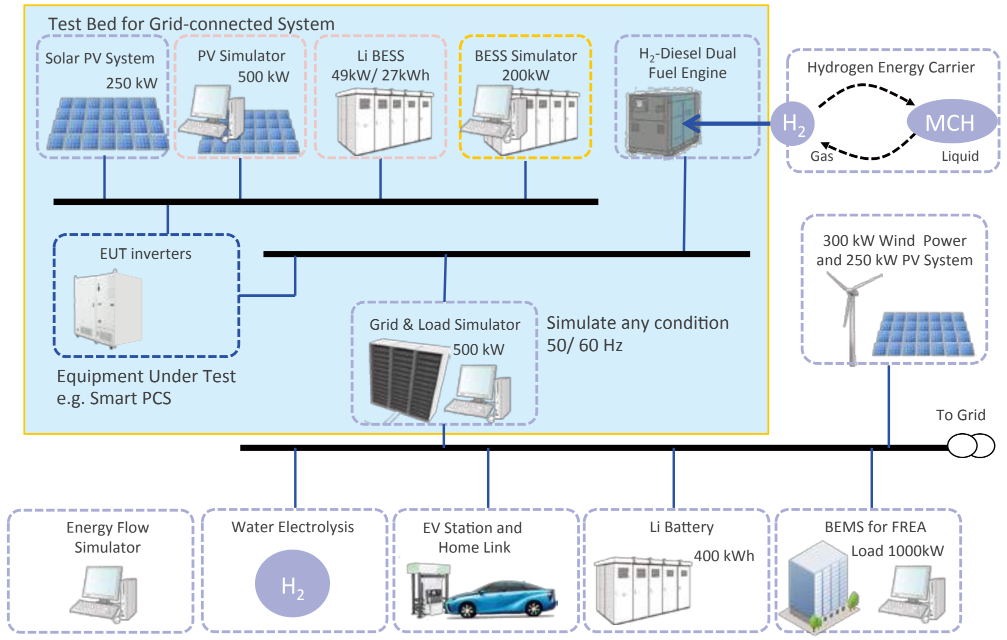
Technological items handled by the Energy Network Team

Main Research Facilities

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

This platform will be used for the development of an energy management system (EMS) and its demonstration through PV systems (consisting of different technologies from ten companies), a large power grid simulator (Smart DER system research equipment consisting of a 500 kW AC grid simulator and two sets of 300 kW DC simulators). In addition, the platform enables hydrogen production technologies using renewable energy in anticipation of the hydrogen society, research and development facilities for distributed batteries such as electric vehicles and EMS evaluation linked with forecast technologies for solar irradiation and wind velocity (EV demonstration facilities, 20 kW class PV + water electrolysis demonstration facilities, etc.).

*DER: Distributed Energy Resources



DER demonstration platform

Activities and Achievements

1) System integration technology and energy management

The team conducted a performance analysis of individual elemental technologies, including ten different types of photovoltaic (PV) systems with three types of twenty-two inverters (PCS: power conditioning systems), a proton exchange membrane type water electrolysis system (with a fuel-cell function), and a hydrogen storage system using metal hydrides; based on this, the team conducted a large number of joint research studies. In the future, the team will promote system research through the demonstration of system integration technologies using power smoothing simulation, hydrogen production with fluctuating renewable energy, and electric vehicles.

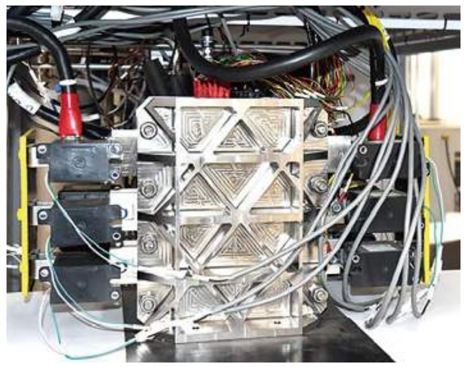


Fig. 1: Unitized reversible fuel cell

2) Advanced monitoring of renewable energy resources

The team developed a renewable energy power generation observation system to better understand the temporal and spatial variability in power generation when PV and wind power generation is introduced in Fukushima Prefecture on a massive scale through the Fukushima Prefecture Renewable Energy Next-Generation Technology Development Project (FY2013–2014). The system makes it possible to estimate the amount of power generation (PV and wind power) in the entire Fukushima Prefecture using a 2-km mesh and an interval of one hour, and 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) Hydrogen production, storage and utilization system using renewable energy

In response to the problem of power output suppression in the case of introducing a large amount of renewable energy, we have developed a hydrogen energy system consisting of a water electrolyzer, storage unit and fuel cell system. We developed the water electrolyzer using photovoltaic output and succeeded in converting 15% of the solar energy into hydrogen energy by direct coupling between photovoltaic and electrolysis (Figure 1).

We are aiming to put the stationary hydrogen energy system into practical use in residential areas. We are developing hydrogen storage using a metal hydride that can store hydrogen safely and easily. Furthermore, we aim to utilize CO_2-free hydrogen for fuel cell vehicles, through the development of technology related to high-pressure hydrogen.

Fig. 2: High-pressure hydrogen device for fuel cell vehicle application development

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Hydrogen Energy Carrier Team

– Production and Utilization Technology for Hydrogen Energy Carrier –

Since renewable energy is unstable and/or highly dependent on the weather and location, the amount of electric power generated by renewable energy is also unstable. The production technologies for hydrogen energy carriers are water electrolysis technology for producing hydrogen using such unstable electric power, and chemical energy conversion technology for electrolyzed hydrogen using a catalyst. These technologies are necessary in order to introduce a large amount of renewable energy.

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 electrolysis, chemical conversion to 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 will lead to technical breakthroughs:

● Technologies for high-efficiency production of hydrogen energy carriers (e.g. organic chemical hydride, ammonia, formic acid). We are developing high-efficiency technologies for catalyst synthesis.

*Methylcyclohexane (MCH): Organic compound containing 6wt% hydrogen, which is liquid at room temperature and atmospheric pressure. One liter of MCH can store 500 L of hydrogen gas.

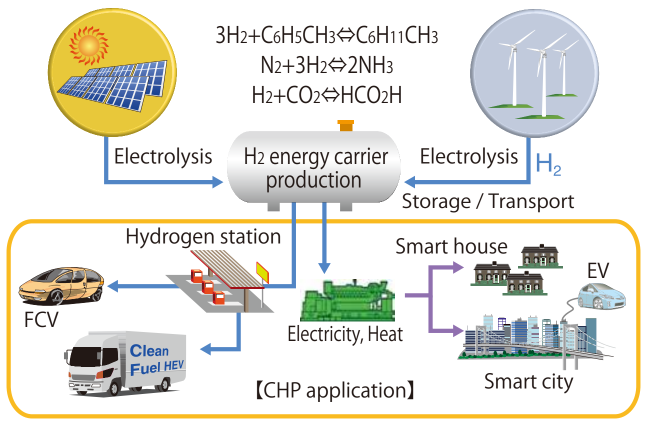
*Ammonia: Nitride containing 17wt% hydrogen, which is liquefied at room temperature and pressure of 0.86 MPa. One liter of liquid ammonia can store 1300 L of hydrogen gas.

*Formic acid: Organic compound containing 4wt% hydrogen, which is liquid at room temperature and atmospheric pressure. Formic acid is produced by synthesizing carbon dioxide and hydrogen. One liter of formic acid can store 600 L of hydrogen gas.

● Technologies on the combustion of hydrogen or hydrogen energy carriers for cogeneration engines and gas turbines.

● Demonstration of an integrated system of hydrogen production/utilization

A new system to optimize the storage and utilization of electric power generated by renewable energy will be proposed through this experiment.



Production and utilization of hydrogen from renewable energy

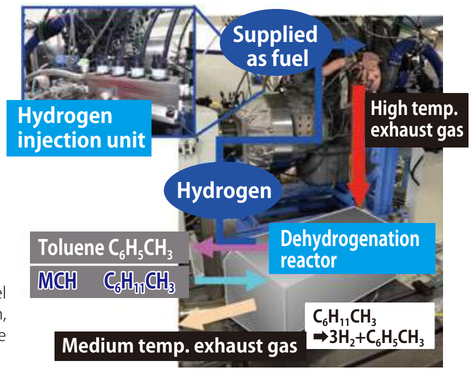
Main Research Facilities

Hydrogenation/Dehydrogenation Reaction Apparatus

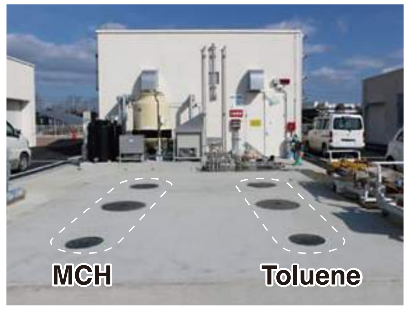
Catalytic hydrogenation and dehydrogenation reactions are analyzed by on-line gas chromatography. Simulated fluctuating hydrogen derived from renewable energy can also be supplied.
Hydrogen flow rate: 10,000 mL/min, toluene and MCH flow rate: 10 g/min

Advanced Cogeneration Engine

Excessive operational experiment and multi-fuel engine combustion technology with hydrogen, diesel fuel, etc., using a 4-cylinder diesel engine (displacement: 5.2 L)



Alkaline water electrolyzer



Large storage tanks

Advanced Cogeneration Engine

Hydrogen Energy Carrier Production/Utilization System

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

Specifications

Hydrogen generation capability by alkaline water electrolysis: 34 Nm³/h
Hydrogenation to toluene: 70 L/h (MCH production capacity)
MCH storage capacity: 20 kL (conversion to power generation: about 10 MWh)
Cogeneration output (electric power and heat): power 60 kW and heat 35 kW

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.

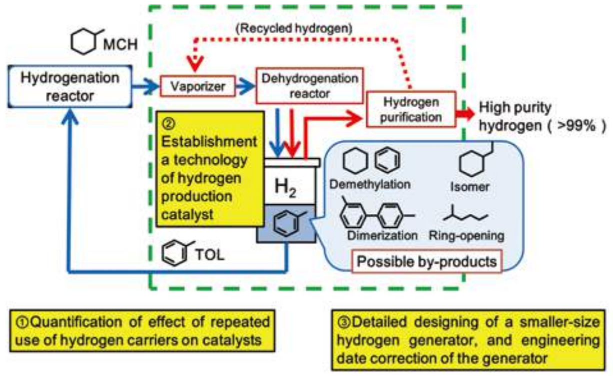


Fig. 1: Hydrogenation and dehydrogenation cycle of MCH

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 was launched. The alkaline water electrolyzer in this system successfully converted 30 MWh of electricity to hydrogen (equivalent to 3000 days of ordinary home electricity consumption), and a new simulator capable of predicting the performance of the electrolyzer has been constructed. In addition, this demonstration system has been incorporated into FREA's energy network and we will propose a strategy for electricity storage and utilization.

3) Advanced cogeneration engine using H_2 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 elevated 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.

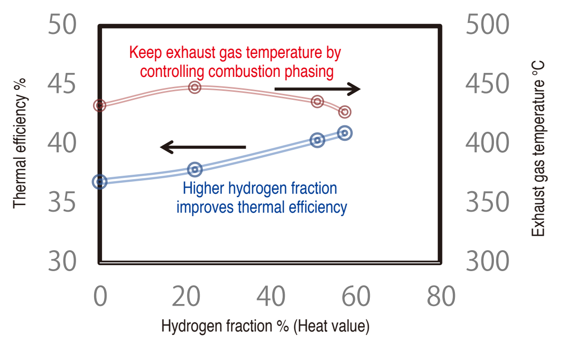


Fig. 2: Thermal efficiency and exhaust gas temperature as a function of the hydrogen ratio of the next-generation cogeneration engine

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: 50 kW), and 41.8 kW power generation was successfully achieved by burning methane-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).

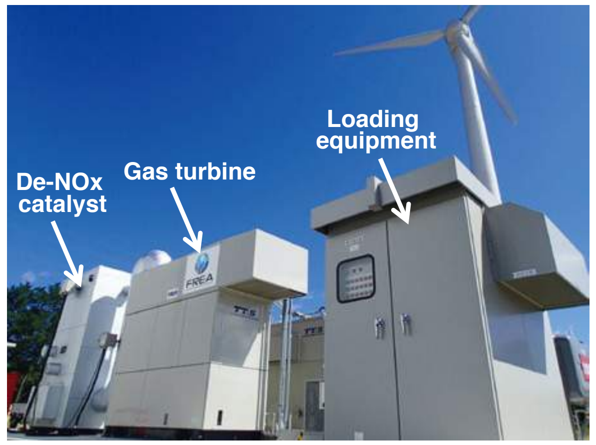


Fig. 3: Ammonia gas turbine

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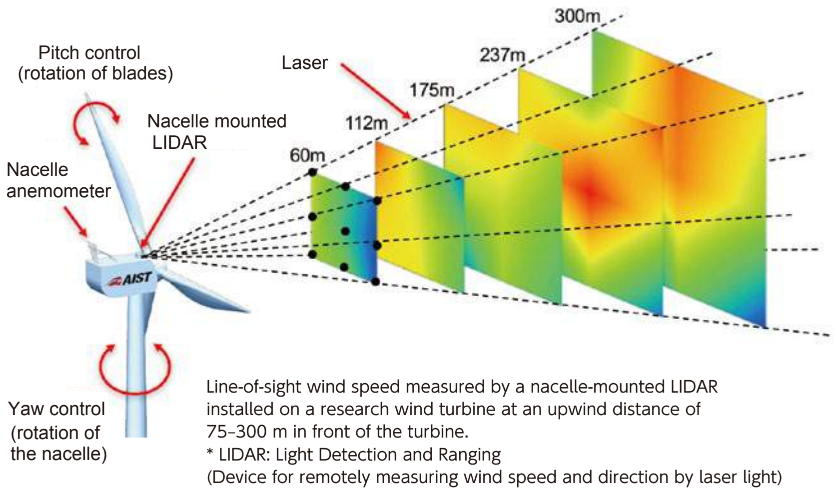
Wind Power Team

– Advanced Technology for Wind Power Generation –

In order to accelerate the introduction of wind power generation and achieve grid parity it is necessary to reduce the cost of wind power generation. This requires the continuous development of the hardware aspect of wind turbine technology, and the software aspect of technologies for the selection of suitable sites and management of wind farms.

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 5–10% 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 annual wind speed and the reduction of assessment costs by 20–30%.



Line-of-sight wind speed measured by a nacelle-mounted LIDAR installed on a research wind turbine at an upwind distance of 75–300 m in front of the turbine.
* LIDAR: Light Detection and Ranging
(Device for remotely measuring wind speed and direction by laser light)

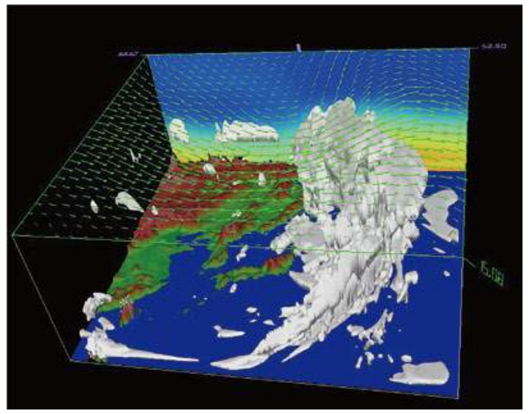
Research Outline

1. Elemental technology for a high-performance wind turbine

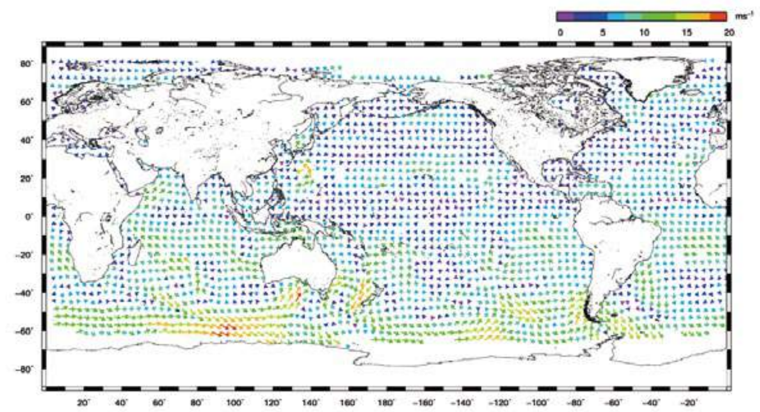
The team has demonstrated a prototype of a nacelle-mounted LIDAR as a new technology for measuring the wind speed and direction upwind of the turbine rotor plane. LIDAR measurement flow and turbine feed-forward control can be combined to optimize the turbine cyclic blade pitch and rotor speed to alleviate 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.



Numerical meteorological model



Wind resource assessment using satellite remote sensing

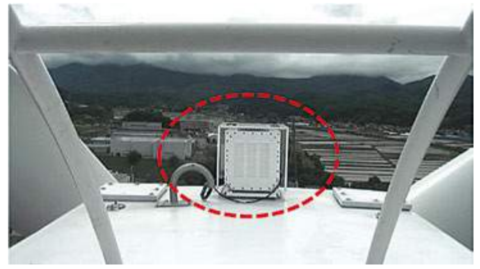
Main Research Facilities

Research wind turbine
Komaihaltec Inc. KWT300

Rated power output: 300 kW, rotor diameter: 33 m, hub height: 41.5 m.
The wind turbine is designed to withstand severe climate conditions in Japan (e.g. a highly turbulent flow from the complex terrain) through the collaborative research of AIST and Komaihaltec Inc.

Prototype of the nacelle-mounted LIDAR

The forward-looking wind LIDAR measures the approaching inflow in front of the research wind turbine with nine sampling directions.



Ground-based LIDAR

The LIDAR system measures the wind speed and direction remotely at the height of 50–200 m above ground.

Satellite and meteorological data processing system

The system provides about 1 petabyte of storage for large-scale satellite and meteorological data, and it also processes the data.

Search device for acoustic sources

The system surveys acoustic sources using 30 acoustic microphones and transducers.

Activities and Achievements

1) Field demonstration results of the nacelle-mounted LIDAR (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 LIDAR. 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 ±10° based on the information about the wind direction in front of the wind turbine obtained with the nacelle-mounted LIDAR.

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 (MOSST) (Shimada et al., 2015), thus significantly improving 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.

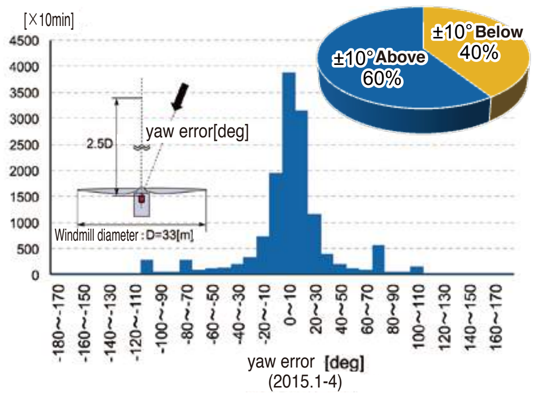


Fig. 1: Histogram of yaw misalignment (error in the wind turbine direction against the inflow wind direction)

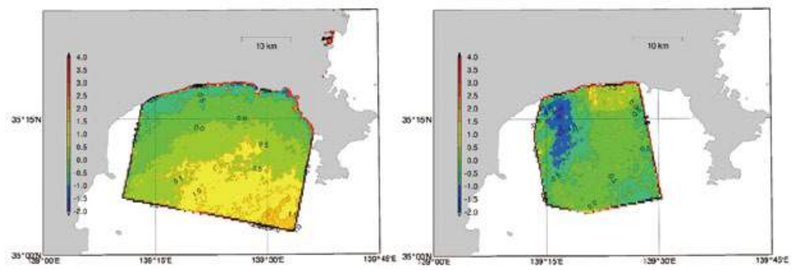


Fig. 3: Difference between measured value from an ocean observation tower (1 km offshore) and retrieved SAR wind speed (Hiratsuka)

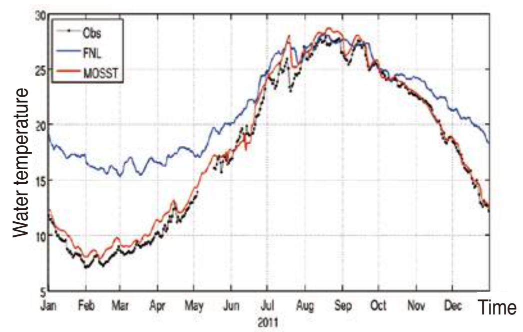


Fig. 2: Comparison between various sea-surface temperature datasets and measured data (Osaka Bay)

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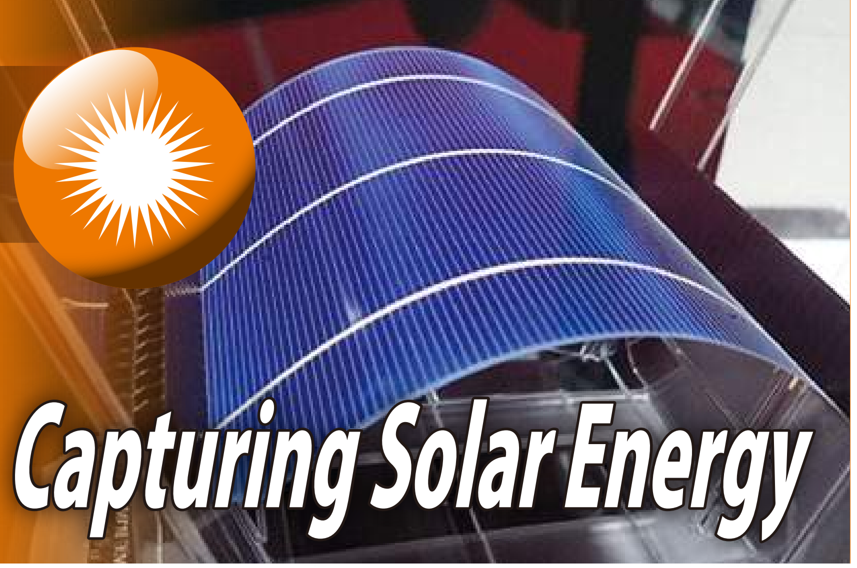
Photovoltaic Power Team

– High-Performance PV Modules Based on Thin Crystalline Silicon Solar Cells –

A large number of photovoltaic (PV) systems have been installed under the Feed-In Tariff (FIT) since July 2012. In addition to the conventional installation on house rooftops, many large-scale or "mega solar" power plants have been constructed. It is very important to reduce the cost of PV power generation in order to reduce the share of the burden on electricity users and to improve the competitiveness of PV modules in the market.



Research Target

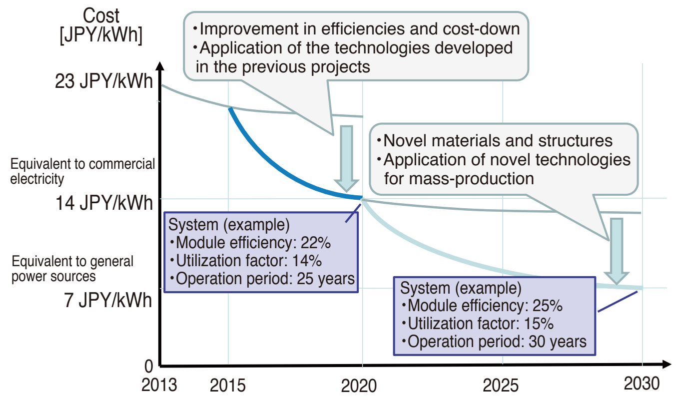
The team addresses the following subjects to develop technologies for producing low-cost, highly efficient and reliable modules (target conversion efficiency: 22%)

● 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 highly efficient solar cells (conversion efficiency higher than 30%). Technologies to achieve the power generation cost target of 14 yen/kWh in 2020 and 7 yen/kWh by 2030 will be developed.



Japan's PV roadmap for 2030 (NEDO PV challenges)

Research Outline

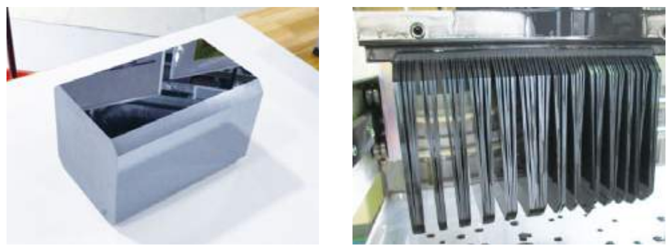
Although crystalline silicon (c-Si) technology has the dominant share in the PV market, its cost must be reduced significantly in order to accelerate the deployment of PV systems.

The team conducts comprehensive research using a semi-production line 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 0.10 mm (from the present cell thickness of 0.18 mm to 0.08–0.10 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 cell processes such as wafer cleaning.



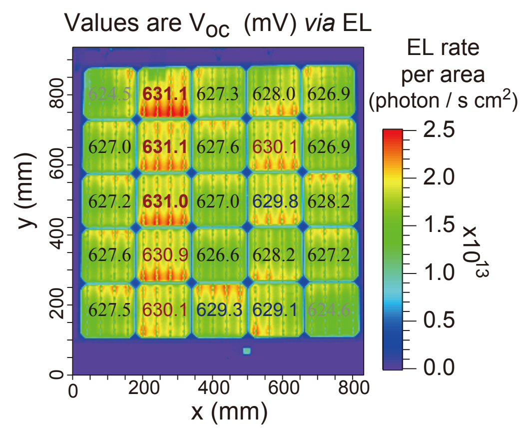
Silicon ingot (left) and appearance after slicing (right) (wafer thickness: 0.12mm)

● Development of new cell fabrication techniques

New cell production processes using the 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 nondestructive module evaluation method through voltage mapping using the absolute electroluminescence (EL) method has been developed. A forward bias is applied to the solar cell and individual cell voltages can be evaluated based on the luminescence intensity of the cells.



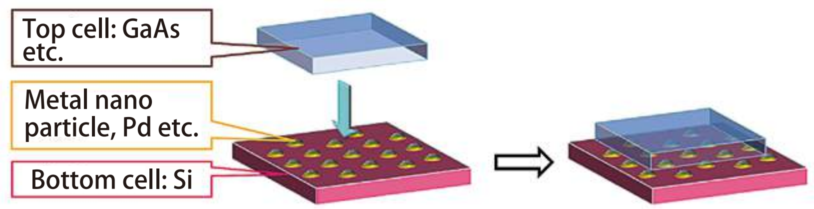
Voltage mapping using the absolute electroluminescence method

● Next-generation multi-junction solar cell "smart stack technology"

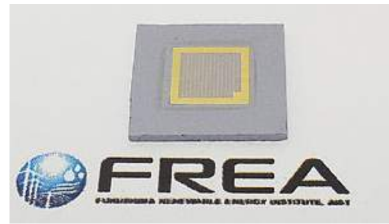
The "smart stack technology" using metal nanoparticle arrays has been developed, making the interconnection of various solar cells with different materials and bandgaps possible for the first time. This provides flexibility in material choice and device design because the mismatch in lattice constants, thermal expansion coefficients, etc. can be disregarded with this technique.

A GaAs/InP-based four-junction solar cell has achieved conversion efficiency as high as 31.6%, and a GaAs/CIGS-based three-junction solar cell has achieved conversion efficiency as high as 24.2% (joint research with the Research Center for Photovoltaics at AIST Tsukuba Center). We are working to improve and establish this technology for mass production.

The use of thin crystalline silicon as a bottom cell provides high efficiency and low-cost multi-junction cells. 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 24.7% has been successfully fabricated.



Smart stack technology



GaAs/Si-based three-junction smart stack cell

Main Research Facilities

Electrode firing furnace

Furnace for forming contacts between the electrode and the diffusion layer as well as Al–BSF layers.

Spin etching apparatus

Apparatus that etches a single side of the wafer by spin rotation. Only one side can be etched without a protective film.

Ion implantation equipment

Equipment that implants accelerated phosphorus or boron ions in the wafer. The diffusion profile can be precisely controlled.

Major Achievements

1) The standard FREA process for the fabrication of Al-BSF type crystalline Si cells was established with an average efficiency of about 19.3%, equivalent to the highest efficiencies reported by companies.

2) The technology for thin wafer (0.12 mm thick) slicing from silicon ingots has been established using diamond wires. Processing conditions close to the mass production of a wafer with a thickness of 0.12 mm have been established with a 99.8% yield.

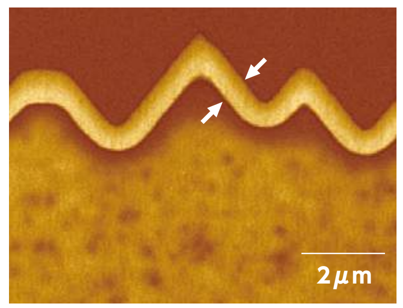
3) The smart stack technology was applied to a GaAs/Si-based three-junction cell to achieve conversion efficiency as high as 24.7%.

4) Industrializable fabrication processes for PERC-type cells and bifacial-type cells were established with efficiencies of 20.5% and 20%, respectively.

5) A diffusion layer with a uniform depth on pyramid-shaped surfaces has been successfully formed by means of ion implantation, demonstrating cell efficiency as high as 19.4%.

6) New cell and module evaluation techniques (absolute EL method and internal quantum efficiency mapping method) were developed. The absolute EL method can be used to visualize energy losses in smart stack cells.

Crystalline silicon cell fabricated by standard FREA process



Phosphorus diffusion layer formed by ion implantation

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Geothermal Energy Team

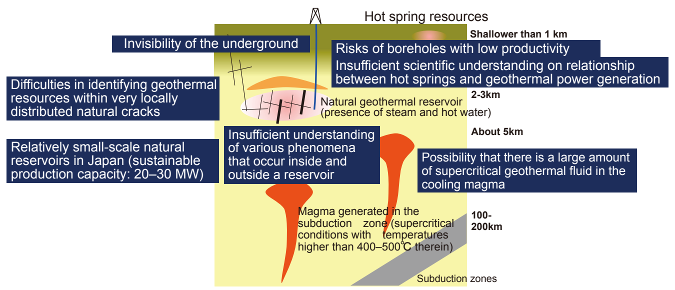
– Technologies for Effective and Sustainable Use of Geothermal Resources –

Japan has many volcanoes and a vast amount of geothermal energy that can contribute to stable power without being affected by the weather conditions. Geothermal energy has the potential to provide the base load power.

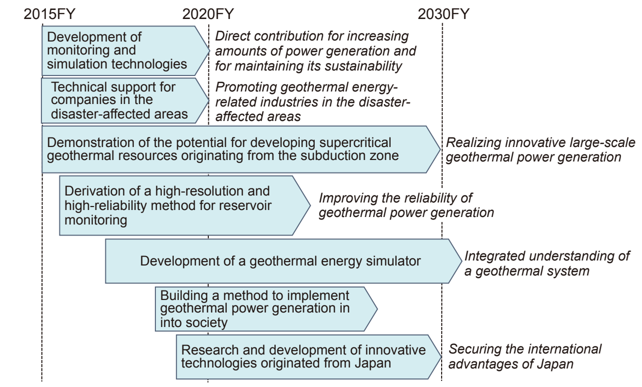
Research Target

The team is conducting research and development for the sustainable use of geothermal energy on a suitable scale and in a proper style according to underground conditions and social situations with the following catchphrase: "Proper use of geothermal energy." In the short term, the team aims to make a direct contribution to sustainable power generation and to increase its amount by developing a monitoring system for the coexistence of geothermal power generation with hot springs and advanced monitoring of changes in the reservoirs.

In the long term, the team will make geothermal energy available on a large scale as a base load power source by developing an innovative power generation technology through the use of supercritical geothermal resources originating from the subduction zone and the development of a method for using geothermal energy in society.



Need for studying and developing geothermal energy



FREA's Geothermal Energy Research Roadmap

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 invisible and the properties of geothermal resources largely 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 Tohoku region.

The team mainly aims to accomplish the following goals:

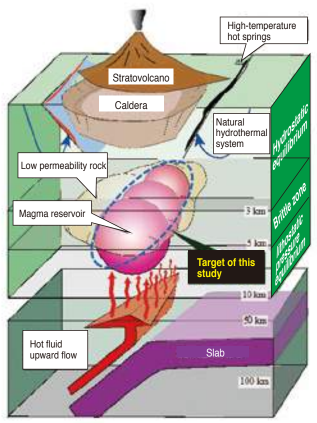
● Understanding and visualizing the phenomena that occur in the reservoir by developing a sensing system for monitoring geothermal energy using microelectromechanical systems (MEMS), optical fibers, etc., and by developing advanced analysis technologies such as transient multicomponent signal processing and integrated interpretation.

● Compiling huge amounts of geothermal resource information possessed by AIST into an advanced database, presenting optimal development methods, and achieving coexistence 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 derive a universal development and utilization method.

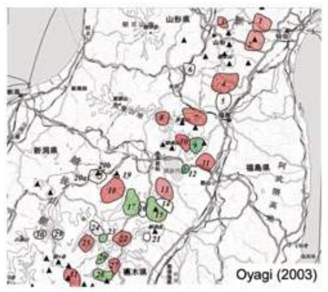
● Exploring the possibility of developing supercritical geothermal resources originating from the subduction zone and making it available for large-scale base load power generation by around 2050.

The team has proposed the possibility of generating several tens to several hundreds of GW of power by exploiting a supercritical geothermal resource originating from the subduction zone. The team is drawing up a research plan to make this geothermal resource available as a base load power source by around 2050.



Concept of a supercritical geothermal system

The results of seismic and other analyses suggest the existence of magma-originated volcanic complexes containing about 1% of the supercritical fluid beneath the old volcano and caldera (4–5 km). There are more than 50 old volcanos and calderas in the Tohoku region.

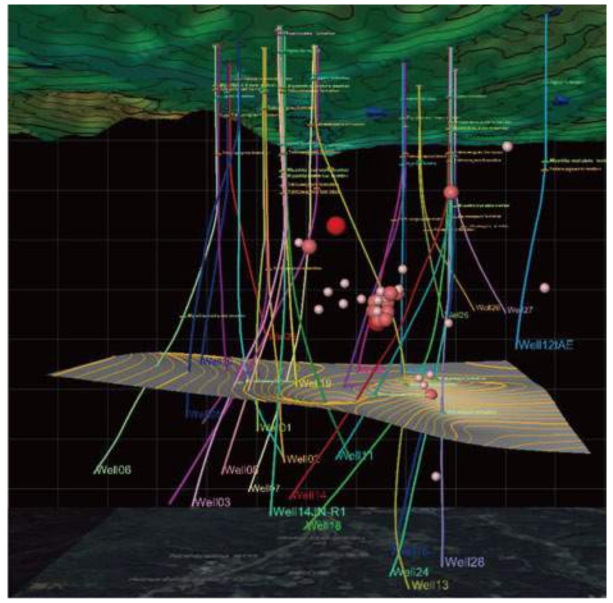


Distribution of old calderas (Oyagi, 2003)

Yanaizu-Nishiyama Geothermal Power Plant (Photo courtesy of Tohoku Electric Power Co., Inc.)

Installation status of three component seismometers

In order to prevent a decrease in steam production and to recover production, water-recharge injection tests have been conducted at the Yanaizu-Nishiyama 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.



Microearthquake data integration and visualization system (monitoring the behavior of the injected water)

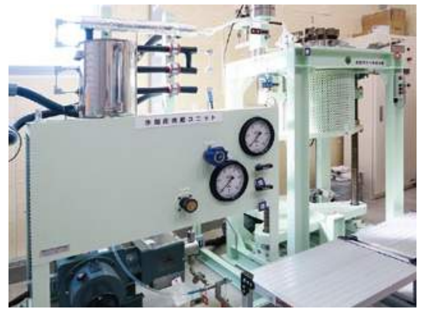
Main Research Facilities

Examination device for hot spring system

The device simulates a hot spring pipeline in the laboratory for evaluating hot spring monitoring sensors and conducting experiments on hot spring

Experimental facility for shear slip of a fracture

This facility enables the simulation of various mechanical phenomena in geothermal reservoirs under high temperature and pressure.



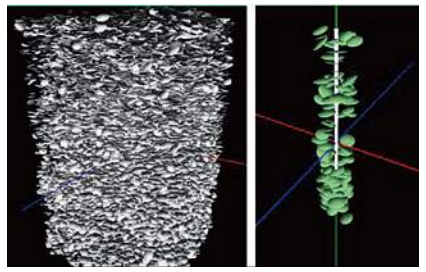
Experimental facility for the development of borehole tools for high-temperature and high-pressure geothermal wells

This facility is capable of simulating 350°C, 60 MPa borehole conditions.

Activities and Achievements

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

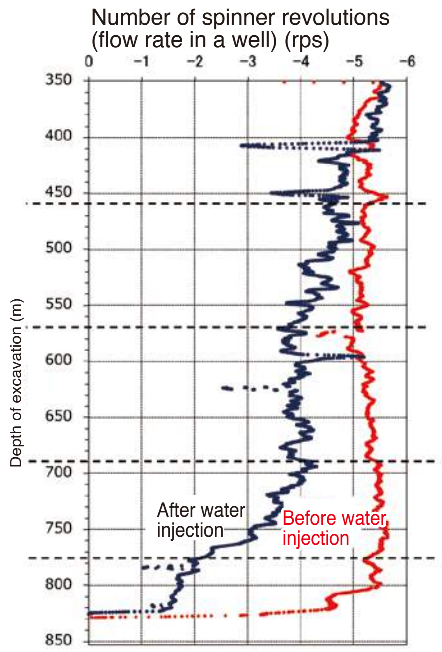
In some cases, the capacity of a geothermal reservoir is improved by injecting water into the reservoir through a geothermal well. The Geothermal Energy Team collaborated with US and European researchers and developed a simulator for investigating the response to a crack for water injection. As a result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



Simulation of a subsurface crack

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 stand-alone measurements and continuously transfers the obtained data to a server through the Internet. The performance evaluations by laboratory experiments and field demonstration tests for practical application will continue to the end of FY2017.



Results of a water injection test

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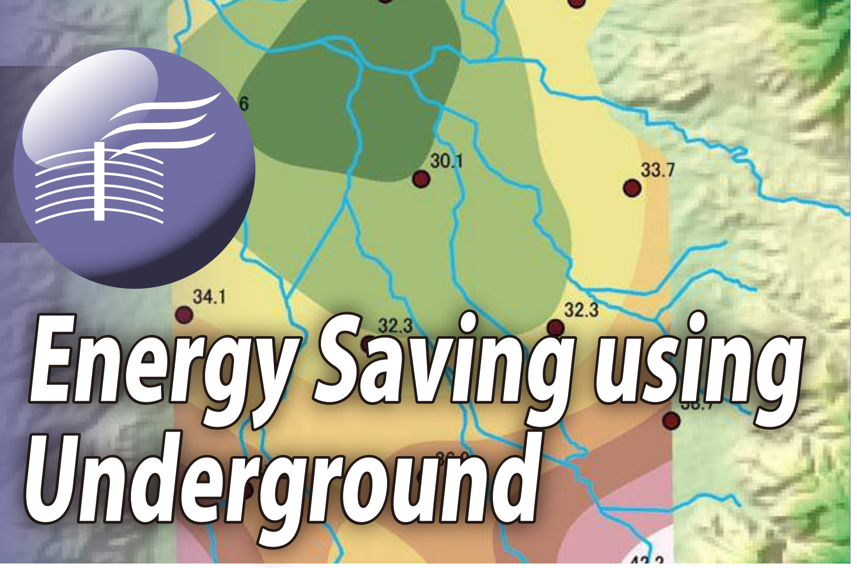
Shallow Geothermal and Hydrogeology Team

– Suitability Assessment of Ground-Source Heat Pump System and Its System Optimization Technology –

A Ground-Source Heat Pump (GSHP) system is a technology that originally spread in western countries in the 1980s after the world oil crisis. Although the technology is not new, its use in Japan has been delayed since it was hardly known until around the year 2000. Because the existence of groundwater and its flow rate largely affects the heat exchange rate, it is important to understand the water level and flow rate of groundwater systems in order to effectively utilize GSHP systems in Japan.

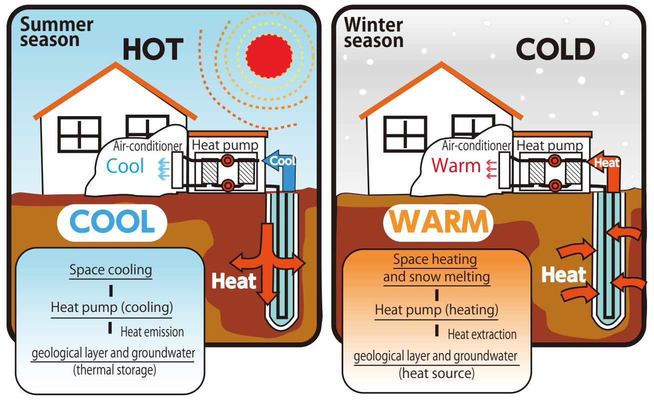


Research Target

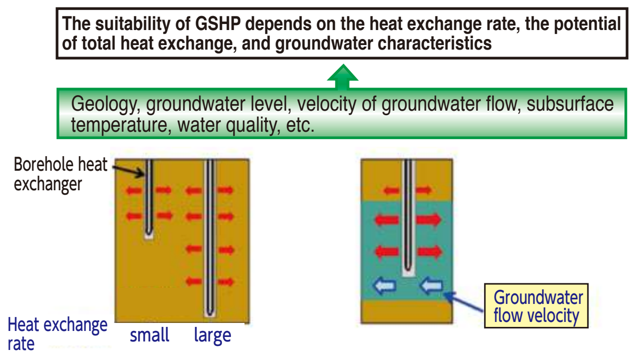
The GSHP system is highly efficient and energy-saving compared to normal air conditioners (air-source heat pump systems). The team has been promoting the GSHP system by enhancing its performance and lowering its cost based on geological information.
There are two types of GSHP systems: a closed-loop system exchanges heat by circulating brine or 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 level 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 designing on optimization technology of a GSHP system
- Expansion of GSHP studies in Southeast Asia and other regions

*COP: Coefficient of performance



Concept of ground-source heat pump system



Suitability assessment technologies for ground-source heat pump application
Suitability mapping for ground-source heat pump (GSHP) systems considering the effects of groundwater is a new idea from AIST.

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 according 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 AIST in Tsukuba City, Ibaraki Prefecture to investigate the differences in heat exchange performance and in optimum heat exchange systems in each area having different hydrogeological settings.

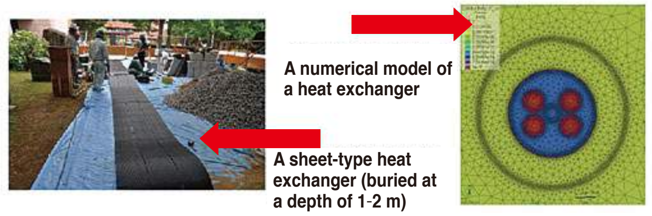
The team is mainly engaged in the following research and development themes:

● Research on GSHP suitability assessment

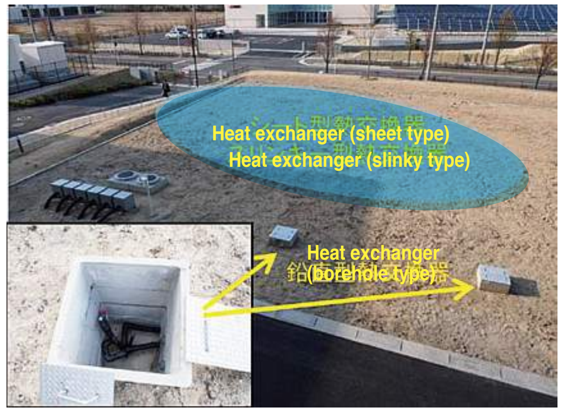
Japan has many regions where there is abundant groundwater at a depth of several meters to a hundred meters, so the utilization of a GSHP system would be more efficient if the groundwater flow is considered. In order to promote the appropriate utilization of GSHP systems, the team conducts research studies in collaboration with Geological Survey of Japan, AIST. The team is also developing methods to assess the suitability of different GSHP systems based on field surveys and numerical analyses.

● Technology development for GSHP systems optimization

The team is evaluating the optimal heat exchange system that can efficiently utilize a shallow (depth: 1–2 m) or deep (depth: about 100 m or less) heat exchanger and is developing a more efficient heat exchange system based on site-specific hydrogeological conditions. At the GSHP experiment field of FREA and at the Geological Museum of AIST in Tsukuba City, identical GSHP systems combining various types of horizontal and vertical heat exchangers are installed to investigate and evaluate the differences between the two areas, having different hydrogeological settings, in the optimal heat exchange method and their efficiency, by long-term monitoring and numerical simulation. Through the "visualization" of the GSHP systems, with a real-time display of the operating state and observation of the heat exchange borehole, the team aims to promote and diffuse the GSHP system.



Main Research Facilities



FREA Ground-Source Heat Pump System Demonstration Area

This GSHP system uses a sheet-type heat exchanger and a Slinky-type heat exchanger installed at a depth of 1–2 m and a vertical-type (borehole type) heat exchanger installed at a depth of about 40 m.

Ground-source heat pump (GSHP) system installed at Chulalongkorn University, Thailand

Facility at Chulalongkorn University in Thailand used to demonstrate the possibility of cooling operation through the GSHP system in Bangkok.
*GSHP: Ground-Source Heat Pump

Activities and Achievements

1) Analysis of the hydrogeological structure of the Aizu Basin

Through joint research with Fukushima University, the team conducted an analysis of the geological structures of the Quaternary layers and of the hydraulic structure (including subsurface temperature distribution) in the Aizu district, Fukushima Prefecture to reconstruct the basic data for assessing the suitability of GSHP systems.

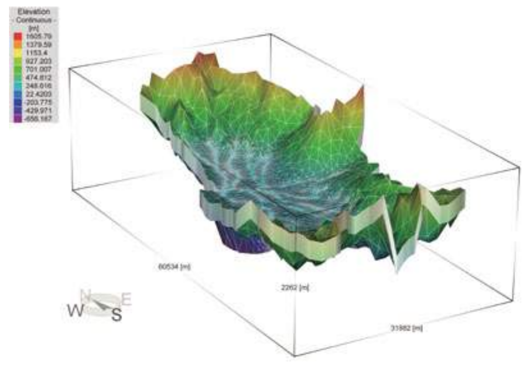


Fig. 1: Three-dimensional groundwater-flow and heat-transport model in the Aizu Basin

2) Suitability assessment for GSHP system installation in Aizu 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 Aizu 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 the regional variation of heat exchange rates, is essential to select the suitable location for the optimum design of GSHP system.

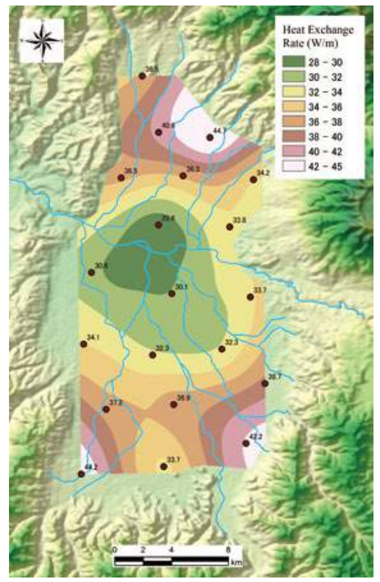


Fig. 2: Distribution map of estimated heat exchange rate in the Aizu Basin

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

The team constructed a closed-loop GSHP system using an artesian well in a joint research project with Japan Groundwater Development Co., Ltd. through the "Program for Promoting Technologies Invented by Industry in Disaster Areas in Tohoku." The team built a system to control the natural flow using the well temperature. COP higher than 8.0 in the cooling operation and COP higher than 4.5 in the heating operation were observed; however, this depends on the operating conditions.

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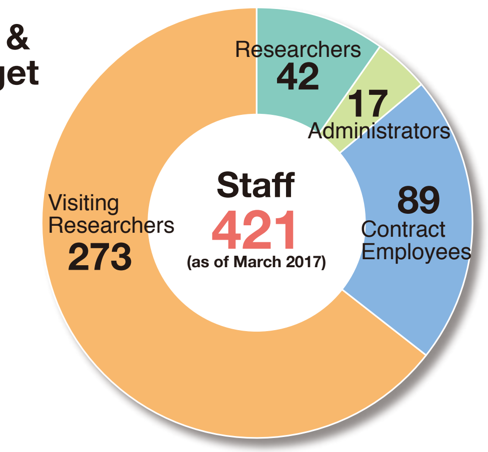
Shallow Geothermal and Hydrogeology Team

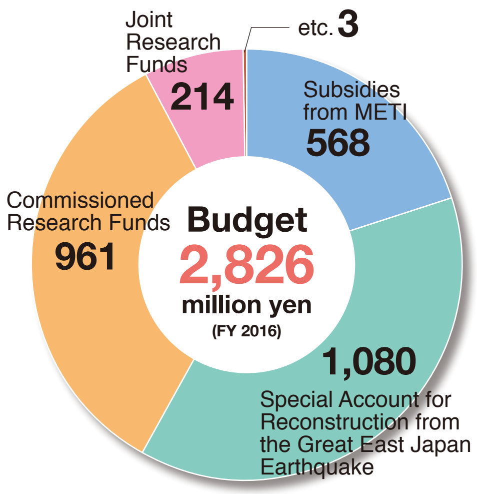
R&D Base

AIST's research base and priority research theme

Total site area ····················78,000㎡
1 Main Building ···················· 7,200㎡
2 Annex Building ·················· 4,700㎡
3 Demonstration Field ··········· 30,000㎡
4 Energy Control Building ··········· 830㎡
5 Smart System Research Facility·· 5,700㎡

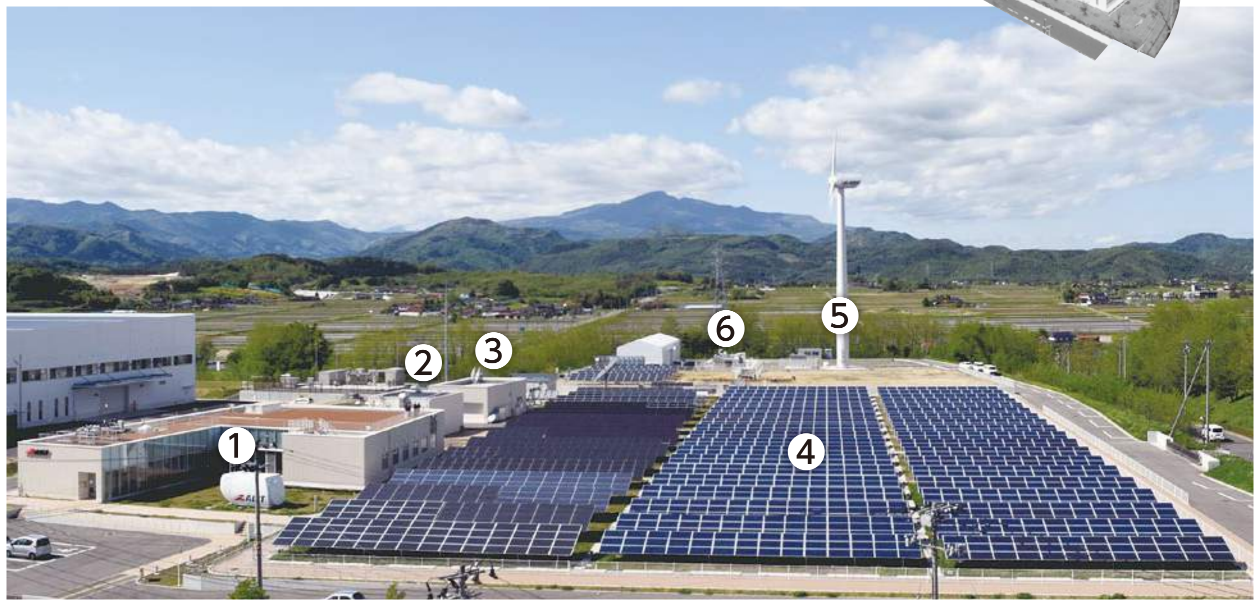
Staff & Budget





Facilities

Demonstration Field



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:
- Power grid simulator (AC simulator: 500 kVA)
- PV array simulator (600 kW)
- RLC load (250 kVA)
- PV power conditioning system (three types, one unit for each type)
- Solar simulator for PV module (simulated sunlight source)
- I-V tracer for PV modules
- EL test device for PV modules
- EMS (Energy Management System)
- SCADA for the PV and wind power systems

2 Hydrogen Energy Carrier Demonstration Building

One of the world's largest MCH production and utilization demonstration systems with an alkaline water electrolyzer, hydrogenation 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 capability by alkaline water electrolysis: 34 Nm^3/h
- Hydrogenation catalyst: 70 L/h (MCH production capacity)
- MCH storage capacity: 20 kL (power generation conversion: about 10 MWh)
- Hydrogen cogeneration output (power and heat): power 60 kW and heat 35 kW

3 Pure Hydrogen Experiment Building

Conducting research on hydrogen energy storage systems and thermal energy storage systems.

Characteristics:
- Proton exchange membrane type water electrolyzer (with fuel-cell function)
- Solar thermal system
- Metal hydride hydrogen storage system
- Quick charger for electric vehicles
- Charge and discharge equipment for electric vehicles (V to Home)

4 Photovoltaic Power System Demonstration Field

Conducting the performance evaluation of a PV generation system as well as the development and demonstration of a control technology for a power conditioner.

Characteristics:
- Rated output: 500 kW
- Solar cell module: total 11 types
- Solar cell module: total 2,500 sheets
- Power conditioner for PV generation (three types, 22 units)
- Area for demonstrating the PV generation system is about 8,000 ㎡

5 Wind Power Generation System

Conducting verification of the Japan-class wind turbine design criteria and a demonstration study on advanced wind turbine control technology. A nacelle-mounted LIDAR is used to develop and evaluate technologies and devices to remotely measure the wind velocity and direction on the upstream side of the wind turbine from above the nacelle. In addition, the team measures and assesses the wind turbine noise using a sound-source surveying device to elucidate the noise properties and also conducts studies on noise reduction.

Characteristics:
- Komaihaltec Inc. KWT300
- Rated power output: 300 kW
- Excellent specifications in wind resistance, lightning resistance, transportation, and workability
- Diameter: 33 m; blade length: 16 m; and hub height: 41.5 m (highest point reached: 58 m)
- Rated wind speed: 11.5 m/s
- Cut-in wind speed: 3.0 m/s, cut-out wind speed: 25 m/s
- Survival wind speed: 70 m/s

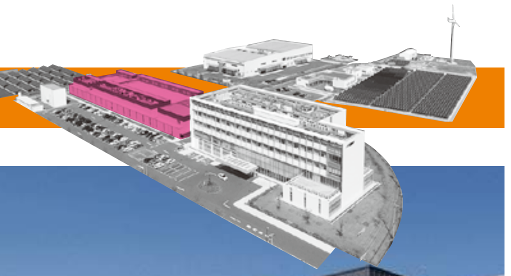
6 Ammonia Direct Combustion Gas Turbine Demonstration Facility

Conducting research and development on the technology for gas turbine power generation that directly burns and uses hydrogen carrier ammonia as fuel.

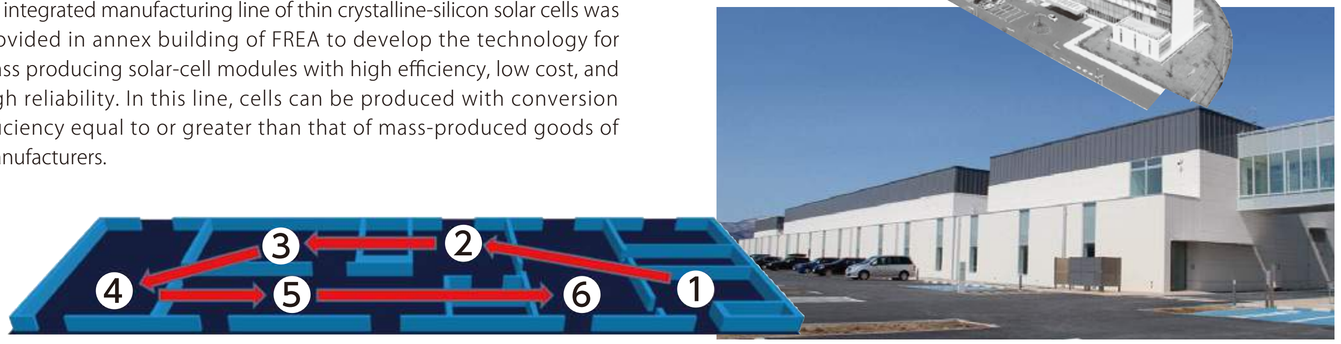
Characteristics:
- Micro gas turbine power generator (rated output: 50 kW (at kerosene operation))
- Ammonia gas, methane gas, or kerosene can be used as fuel.
- The team achieved gas turbine power generation of 41.8 kW by burning methane-ammonia mixed gas. Moreover, 41.8 kW of power was successfully generated by burning only ammonia (100% ammonia) as a fuel (the world's first success).
- The concentration of nitrogen oxide 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 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)

Multi-Wire Saw

2 Surface Texture Formation

Surface Texture Formation Machines

3 PN Junction Formation

Thermal Diffusion Apparatus

Ion Implantation Machine

4 Antireflection Film Deposition

PE-CVD Machine

5 Electrode Printing and Firing

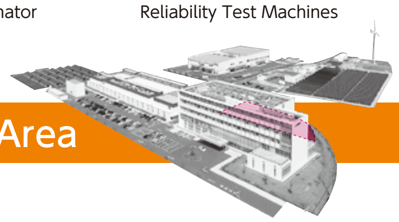
Electrode Printing and Firing Machine

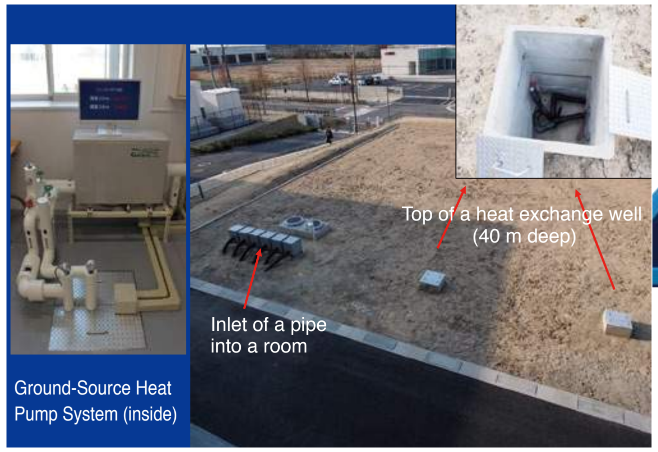
6 Photovoltaic Module Fabrication and Reliability

Vacuum Laminator

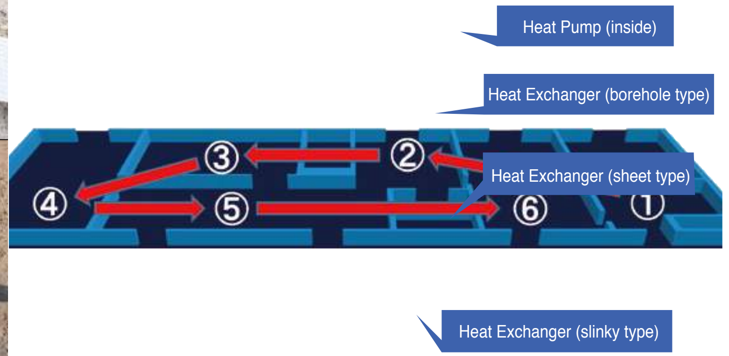
Reliability Test Machines

Ground-Source Heat Pump System Demonstration Area





Overview of Ground-Source Heat Pump System Demonstration Area



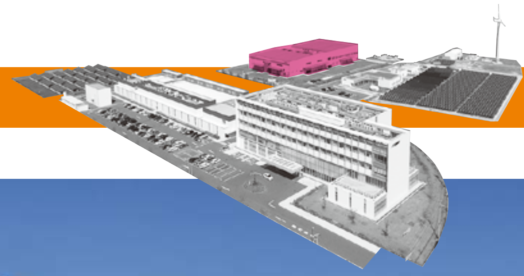
Installation state of underground heat exchanger

At the demonstration test site for the geothermal heat utilization system at FREA, two GSHP systems are installed, one using a sheet-type and a Slinky-type heat exchanger installed at a depth of 1–2 m under the ground and the other using a vertical-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.

A real-time monitor is also installed to display the underground temperature, COP (performance indicator) of the system, room temperature, and other parameters in real time. The team aims to diffuse and promote the geothermal heat utilization system through the "visualization" of real-time operating conditions and part of the heat exchange wells.

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. This national facility enables integrated megawatt-scale research and development of the components, systems and strategies required to safely and efficiently penetrate DER into the grid. The facility will provide globally consistent test results and drive international standardization through international cooperation. We will also support international evaluation of the products through these activities. The main facility has the following four test capabilities.

Grid Connection Testing Facility

Grid Connection Testing

Japan's largest grid connection test facility. Accepts a 20-foot-long container and is capable of supplying 5.0 MVA grid conditions using 3.0-MW DC simulators with/without an emulated power distribution line.

Grid (AC) Simulator

RLC Load Simulator

Safety and Reliability Testing

A large-size 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 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. The facility is used in electromagnetic compatibility (EMC) tests for power electronics devices and ICT devices, which are indispensable for smart grid systems.

Electromagnetic Wave Anechoic Chamber

Environmental Test Lab.

System Performance Testing

Integrated DER system testing facility. This facility will provide the testing environment for the Energy Management System (EMS) using advanced smart technology such as the combination system of PV and ESS with a smart inverter, automated control system of DERs and various other performance tests for integrated systems.

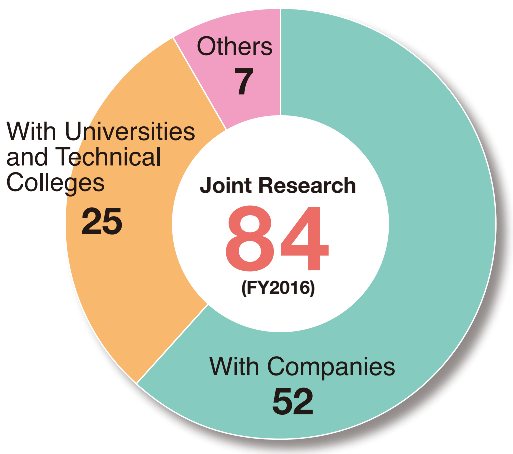
Power to Alliance

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.



Technical Advice

Requests for technical advice or face-to-face meetings are received by email, telephone and regular mail.

Total: 30

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.

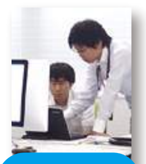
Total: 20

Transfer of IP

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

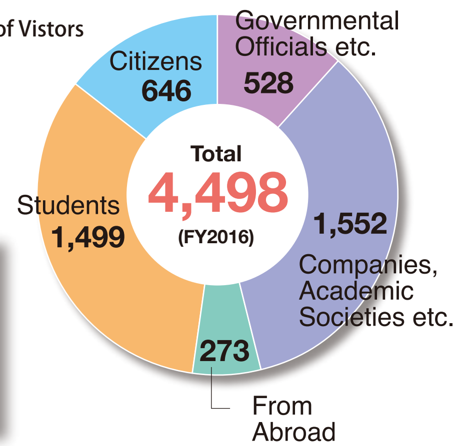
Technical Training

We offer seminars and intensive training on specific technologies necessary for R&D to participants sent from companies and universities, etc.



Total: 39

Laboratory Tour



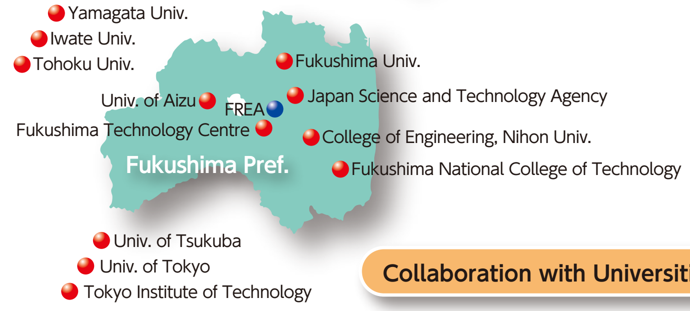
Sending of Experts

We send our researchers as speakers/lecturers upon request.

Total: 20

Collaboration with Research Organizations

FREA actively collaborates with local universities and major research organizations in Japan and abroad. FREA offers its own research personnel, advanced research facilities and wide network to strengthen ties with our research partners.



Collaboration with Universities, etc.

International Cooperation

Europe
- AIT (Austria)
- CNRS (France)
- RSE (Italy)
- Fraunhofer (Germany)
- ECN (Netherlands)
- IFE (Norway)
- NTNU (Norway)
- SINTEF (Norway)
- ELECTRA
- SIRFN

North America
- UBC (Canada)
- LANL (USA)
- LBNL (USA)
- NREL (USA)
- SNL (USA)
- SIRFN

Asia · Oceania
- CSIRO (Australia)
- GA (Indonesia)
- TISTR (Thailand)
- NSTDA (Thailand)
- ERIA
- CCOP

Activities for Open Innovation

Promotion of International Collaboration

The Global Alliance for Solar Energy Research Institutes (AIST, 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

As outreach activities, FREA holds symposia for reporting research results and participates 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 FREA participates in the activities of the Fukushima Renewable Energy Related Industry Promotion Research Society and exhibits at events for 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

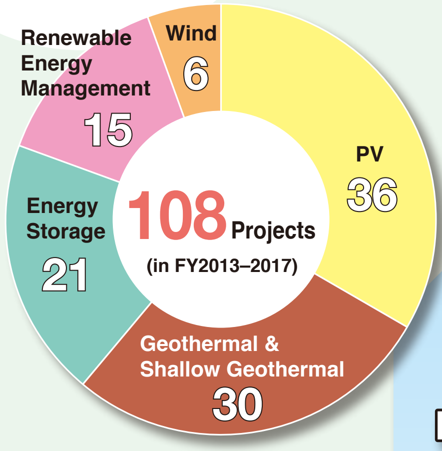
■Objectives and Program Outline

FREA actively supports the companies located in the disaster areas (Fukushima, Miyagi, Iwate Prefectures) by doing joint research not only for solving technical problems but also for establishing new business. As a result of the ongoing program, there have been several success cases, and some have already been launched as commercial products.

Number of Projects to date

FY2013: 11
FY2014: 27
FY2015: 25
FY2016: 19
FY2016: 26

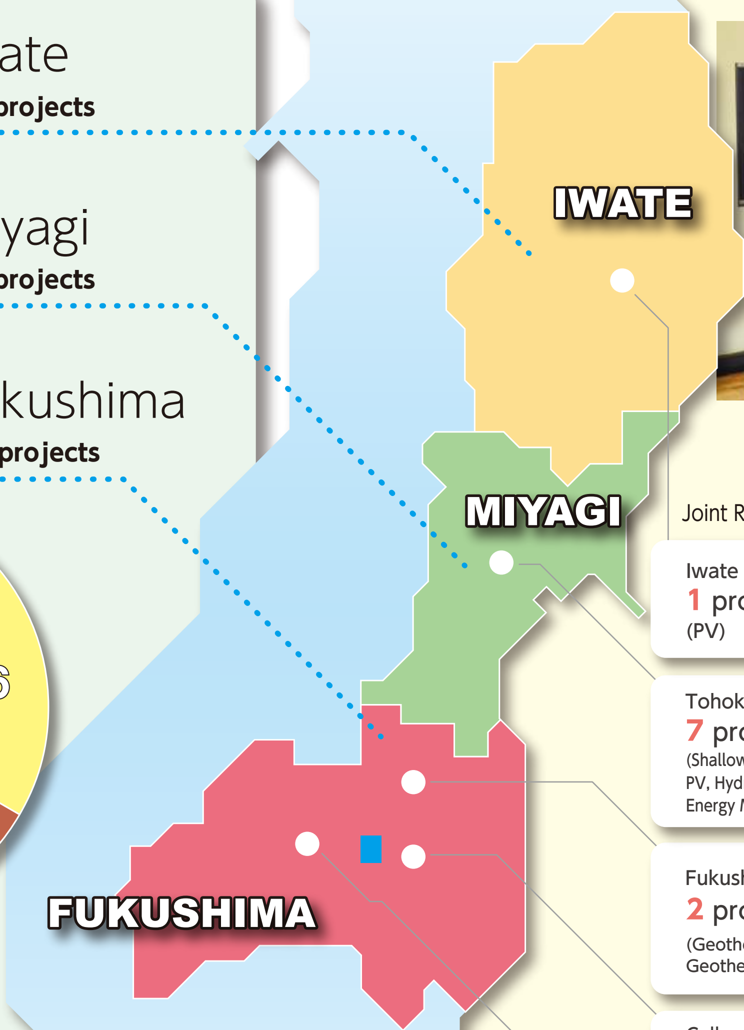
Total: 108 projects



Iwate
11 projects

Miyagi
15 projects

Fukushima
82 projects



Examples of Commercialization

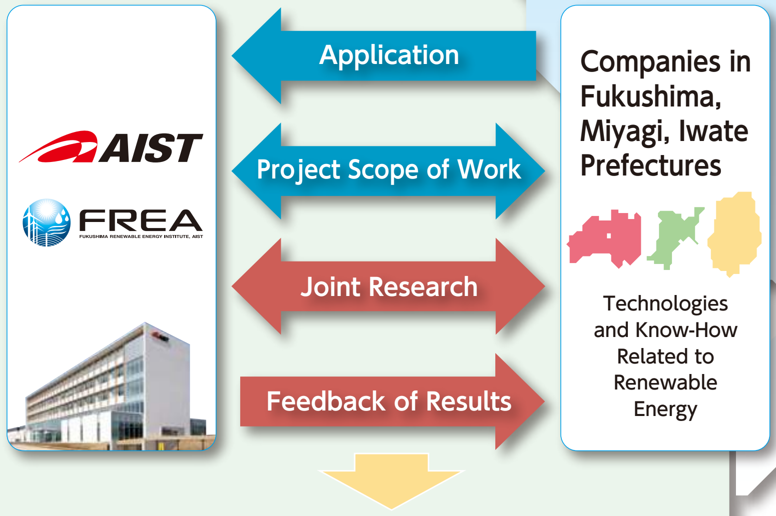
High-performance crosslinking coagent for EVA encapsulants in PV modules by Nippon Kasei Chemical Co., Ltd.

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.

Project Flow



Creation of New Products/Business

Joint Research in FY2016

Iwate Univ.
1 project
(PV)

Tohoku Univ.
7 projects
(Shallow Geothermal, PV, Hydrogen, Renewable Energy Management)

Fukushima Univ.
2 projects
(Geothermal, Shallow Geothermal)

College of Engineering, Nihon Univ.
4 projects
(Renewable Energy Management, Wind)

Univ. of Aizu
1 project
(Renewable Energy Management)

Industrial Human Resources Development Projects

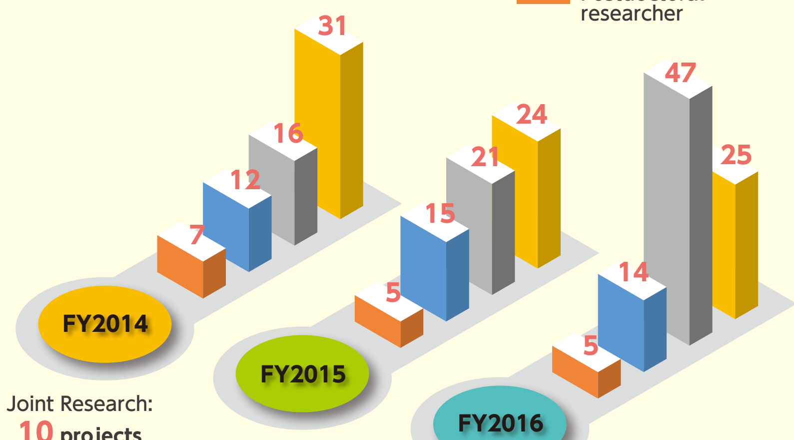
FREA has been providing opportunities for human resource development since FY2014 in renewable energy field for local university students through collaborative research and development activities.

Training Scenes

Visit to binary cycle power plant at hot spring

Presentation by RA at Exhibitions

Achievement



Joint Research: 10 projects

Joint Research: 11 projects

Joint Research: 15 projects

RA

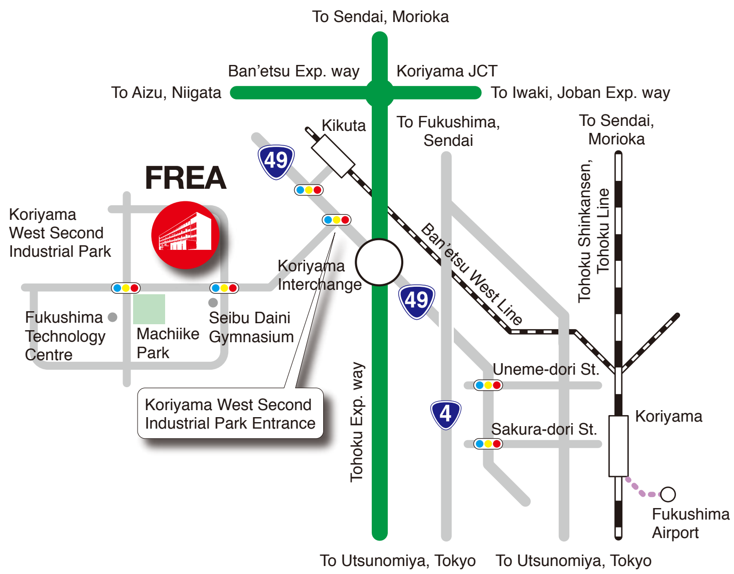
■Research Assistant Program

AIST has a program for hiring graduate 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 "Koriyama 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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