

Renewable Energy Research Center (RENRC)





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Japan's energy self-sufficiency ratio has dropped significantly up to about 6% after the Great East Japan Earthquake in March 2011. Improving the energy self-sufficiency ratio is one of the most important issues for stable and reliable energy supply. The issues on energy mix have been discussed extensively, and the policy goal of securing the self-sufficiency ratio has been set to be around 25% by 2030.

Deployment of renewable energies can contribute to improve the energy self-sufficiency ratio as well as to reduce the CO₂-emission. The share of renewable energy is currently only 10.7% of the total electricity in Japan (including 8.5% by hydropower), and the renewable energy share toward 22%–24% by 2030 has been proposed. In order to accelerate the mass deployment of renewable energy, the low-cost and environment-friendly technologies have to be developed.

The Fukushima Renewable Energy Institute, AIST (FREIA) started operation in Koriyama City, Fukushima Prefecture on April 1, 2014 with two core missions of “Promotion of R&D of renewable energies” and “Contributions to the industrial cluster formation and reconstruction of the disaster struck area”.

The Renewable Energy Research Center (RENRC) is the research unit which is engaged in R&D of renewable energy technologies in FREIA. RENRC consists of six research teams (Photovoltaic (PV) Power, Wind power, Hydrogen carrier, Geothermal, Shallow geothermal and hydrogeology, and Energy network) with 36 full-time staff members (as of October 2015) and a research budget of about 2.9 billion JPY (FY2014).

RENRC runs the following research topics aiming for the high penetration and sustainable growth of renewable energy.

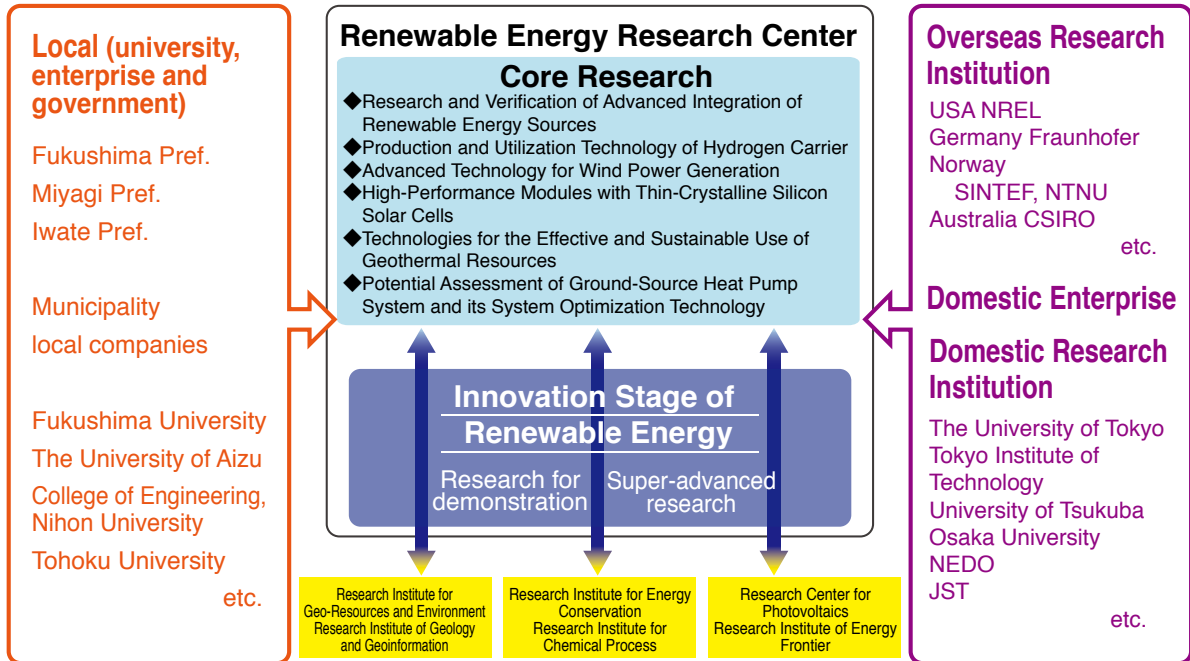
- Make breakthroughs in each renewable energy technology and develop smart system integration techniques
- Significant reduction of power generation costs and improvement in utilization efficiencies of PV power generation system.
- Develop the technologies for appropriate use of geothermal resources and ground-source heat pump systems.

Our goal is to establish highly independent, cooperative and cost-competitive renewable energy technologies.

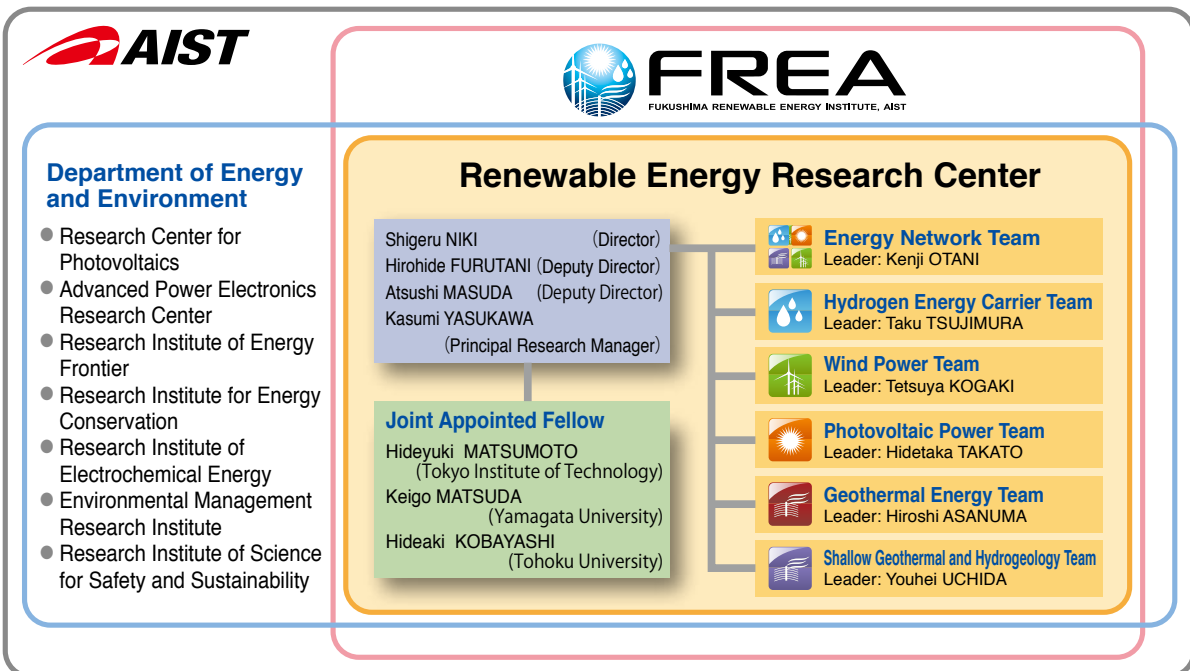
The researchers who have technologies and knowledge critical for the acceleration of R&D have been added; 58 concurrent AIST researchers from other regional research centers and 3 university professors through the cross appointment system.

As an international innovation hub of renewable energy, we promote the collaborations with domestic and international research organizations, and contribute to the development of the industrial clustering and human resources.

Renewable Energy Research Initiative



Organization Chart



Energy Network Team



— Research and Verification of Advanced Integration of Renewable Energy Sources —

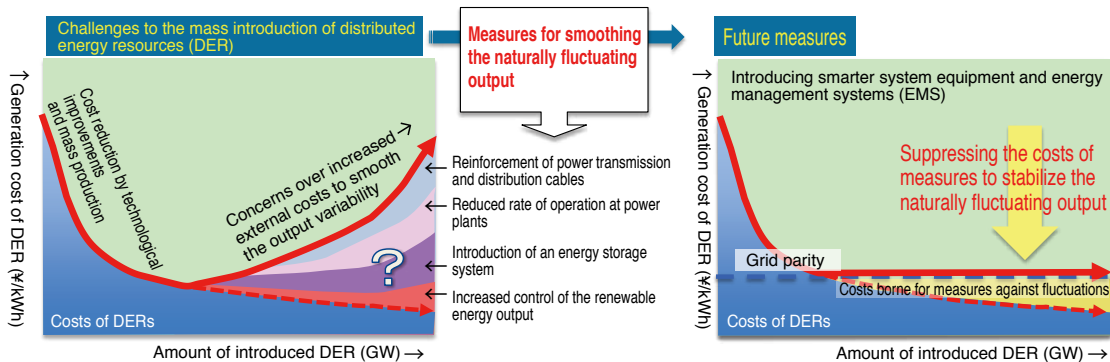
To realize the high penetration of distributed energy resources (DERs) into energy networks, adjusting the simultaneous balance of intermittent DER supply and energy demand is essential by using existing power plants and energy storage systems. The combination of appropriate DER is also important according to each location, because DERs are strongly depend on their locations.

Research Target

To reduce the consumption of exhaustible energy resources (fossil fuel and others) and the CO₂ emissions through the utilization of renewable energy, this team will develop a renewable energy network to reasonably and effectively introduce renewable energy into the existing energy network. In particular, it studies the smart control of power conditioners (PCS), the utilization of energy-storage systems with hydrogen and batteries, and a technology of system integration for multiple distributed energy resources as technologies for achieving both stabilization of the output and maximization of the electric power generation in introducing naturally fluctuating electric power supplies (PV and wind power generations) into the existing energy network.

This team proposes a new energy supply model that builds a renewable energy network combining large-scale PV generation and electricity storage with hydrogen and batteries and that builds on the perspectives of electricity users through flexible demonstration facilities and our test platform.

- Make distributed energy resources (DERs) smarter by using advanced power electronics equipment such as Power Conditioning System (PCS).
- Optimize the system integration by using information and communications technologies (ICTs) with meteorological data.
- Produce hydrogen from renewable energy and develop technologies related to it.



Solving problems regarding the stabilization and countermeasure costs for mass introduction of renewable energy

Research Outline

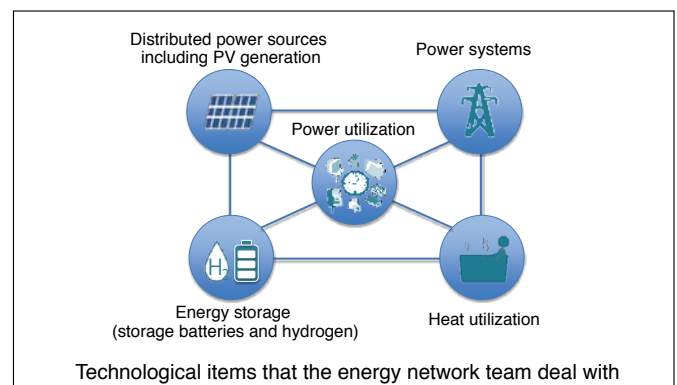
The team is developing a performance test method for elemental technologies such as distributed power sources, power storage systems, and users' apparatuses and a technology for the integrated use of renewable energy in combination with power storage systems and heat utilization technologies in order 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 engaged in the following research and development topics:

- Comprehensive evaluation of a PV generation system: predicting the annual amount of power generation of various types of solar batteries, power-conditioner performance tests, field failure diagnosis of a mega solar, etc.
- Production, storage, and use of hydrogen using renewable energy: a direct electrolysis technology from solar batteries (a solid polymer-type water electrolyzer with a fuel-battery function), hydrogen storage by metal hydrides, compression, hydrogen-separation membranes, solar heat utilization and heat storage technologies, etc.
- Power system coordination and upgrading technologies for distributed power sources: the team will build user facilities to conduct performance

tests of the distributed power sources and performance verifications of EMS that integrate them on an actual scale.

- International standardization: It aims at rapid international standardization of the above development results through cooperation with international research institutes and the like.



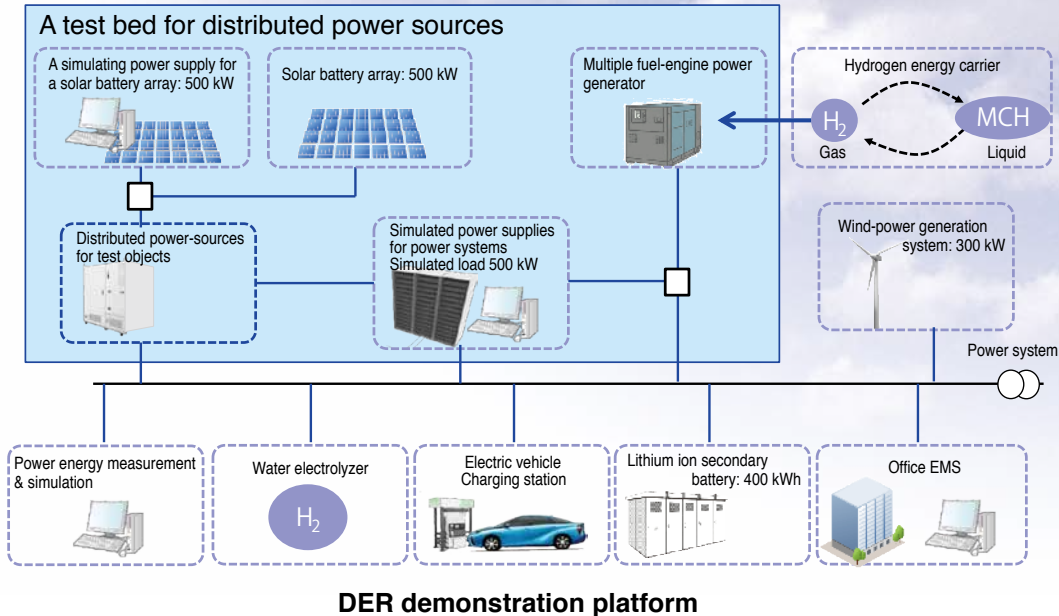
Main Research Facilities

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

On this platform, EMS (Energy Management System) can be developed and demonstrated through PV systems that consists of different technologies from ten companies), large power grid simulator (Smart DER System Research Facility up to 500 kW). In addition, it is a platform enabling hydrogen-producing technologies with renewable energy in

anticipation of hydrogen societies, research and development facilities for distributed batteries as represented by electrical vehicles, and the EMS evaluation linking with forecast technologies for the solar irradiation and wind velocity (EV demonstration facilities, 20-kW-class PV + water electrolysis demonstration facilities, etc.).

※DER: Distributed Energy Resources



Recent Activities and Achievements

①System integration technology and energy management

The team conducted a performance analysis of individual elemental technologies, including a solar photovoltaic power system comprising more than ten types of photovoltaic modules and three types of 22 power conditioning systems (PCS), a solid polymer water-electrolyte system (with a fuel-cell function), and a hydrogen-storage system using metal hydride; based on this, the team conducted a large number of joint researches. In the future, the team will promote the system research, including the demonstration of system integration technologies through the demonstration of power smoothing utilizing simulation technologies, hydrogen manufacturing with fluctuating renewable energy, and electric vehicles.

②Advanced monitoring of renewable energy resources

The team developed a renewable energy power-generation observation system (Fig. 1) to understand the temporal and spatial variability in power generation when PV and wind power generations are introduced within Fukushima Prefecture on a massive scale through the Fukushima-Prefecture Renewable Energy Next-Generation Technology Development Project (FY2013–FY2014). It allows the estimation of the amount of power generation (PV and wind power) in the entire Fukushima Prefecture with a mesh of 2 km and an hour interval and also the forecast of power generation several hours in advance with the same model. In the future, the team will further improve its accuracy to consider the nationwide expansion of this system in Japan.

③A system of producing, storing, and utilizing hydrogen with renewable energy

The team developed an operational technique and a water electrolyzer (Fig. 2) to directly connect solar photovoltaic modules with a solid polymer water electrolyzer to produce hydrogen at the optimal operational point. In the future, the team will be promoting technological development for reducing hydrogen producing costs with renewable energy. The team will aim at realizing the dissemination of FCV and the realization of hydrogen societies by developing related technologies.

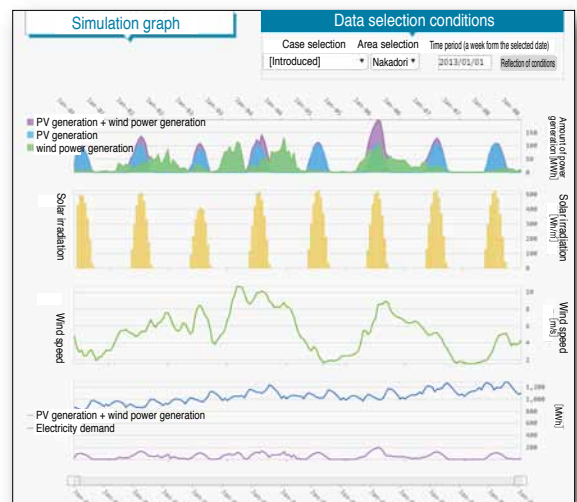


Fig.1: Renewable-energy power-generation observation system (<http://www.solar.fukushima.jp>)



Fig.2: Water Electrolyzer

Hydrogen Energy Carrier Team



— Production and Utilization Technology of Hydrogen Energy Carrier —

Renewable energy such as sunlight and wind power is clean natural resource which is significantly valuable for Japan due to that most of energy resource consumed in Japan is imported from foreign countries. However, since renewable energy is unstable and quite depends on weather and place, amount of electric power acquired with renewable energy is also unstable. Production technologies of hydrogen energy carrier are water electrolyzation technology to produce hydrogen with such unstable electric power, and chemical energy conversion technology of electrolyzed hydrogen with catalyst. These technologies are necessary to introduce a large amount of renewable energy.

Research Target

The team has great challenges to solve energy issues by developing technologies of energy storage and utilization for a massive penetration of renewable energy in the future.

We have been developing technologies on energy conversion of renewable electricity into hydrogen or hydrogen energy carrier which is utilized by generating electricity and heat or is utilized as a fuel for

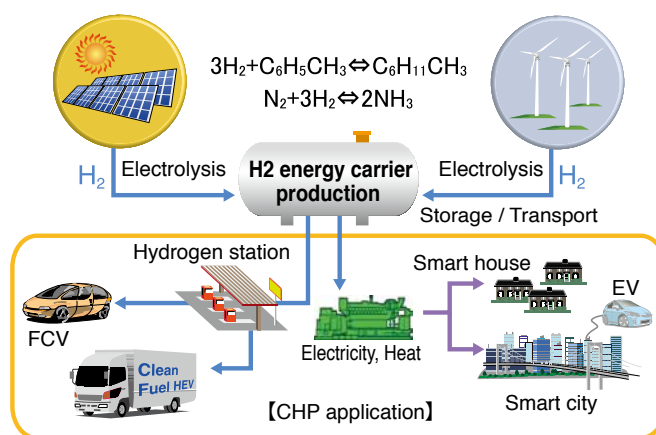
vehicles. These technologies are quite useful to stabilize storage and to supply renewable electricity generated by using renewable energy which is susceptible to change of weather. It will be consequently achieved that much more renewable energy can be used efficiently regardless of locations and seasons, and can solve energy security issues in the future.

Research Outline

The team has been developing a set of hydrogen technologies using electric power generated by fluctuating renewable energy: hydrogen production of water electrolysis, chemical conversion into hydrogen energy carrier, and utilization of hydrogen. The basic technologies such as production of hydrogen energy carrier and catalysts for that, and hydrogen engines are applied to large scale demonstration equipment, and the knowledge gained through the experiments will achieve a technical breakthrough:

- Technologies for high-efficient production of hydrogen energy carriers (e.g. organic chemical hydride, ammonia). We are developing high-efficient technologies for the catalyst synthesis.
 - ※Methylcyclohexane (MCH): Organic compound containing 6 wt% hydrogen, which is liquid at room temperature and atmospheric pressure. One L of MCH stores 500 L of hydrogen gas.
 - ※Ammonia: Nitrogen compound containing 17 wt% hydrogen. One L of ammonia stores 1300 L of hydrogen gas.
- Technologies on combustion use of hydrogen or hydrogen energy carriers for co-generation engines and gas turbines.
- Demonstration of an integrated system of hydrogen production/utilization. A new system to optimize storage and utilization of electric power

generated by renewable energy will be proposed through this experiments.



Energy network including hydrogen energy carrier

Main Research Facilities



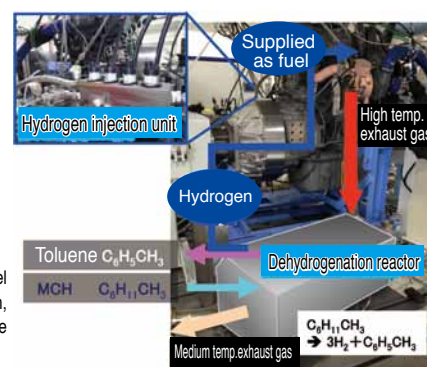
Hydrogen flow rate -10,000mL/min, Toluene and MCH flow rate-10g/min

Hydrogenation/Dehydrogenation Reaction Apparatus

Catalytic hydrogenation and dehydrogenation reaction are analyzed by on-line gas chromatography. Fluctuating hydrogen simulating derived from renewable energy also can be supplied.

Advanced Co-generation Engine

Excessive operational experiment and multi-fuel engine combustion technology with hydrogen, diesel fuel, etc by use of 4 cylinder diesel engine (Displacement: 5.2L)





Large scale alkaline water electrolyzer



Large tanks



Advanced Co-generation Engine

Hydrogen Energy Carrier Production/Utilization System

The world largest class MCH production and utilization demonstration. This demonstration system integrates large scale alkaline water electrolyzer, catalytic hydrogenation reactor, large storage tanks, and co-generation engine with catalytic dehydrogenation reactor.

[Specification]

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

Recent Activities and Achievements

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

Over a hundred kinds of products and their concentration have been analyzed quantitatively by using a catalyst evaluation apparatus with an on-line GC. Developing a design guideline of a production process of organic chemical hydride and collecting data for standardization in the future market. At the moment, analyzing behaviors of products and by-products formation by circulating processes of hydrogenation and dehydrogenation.

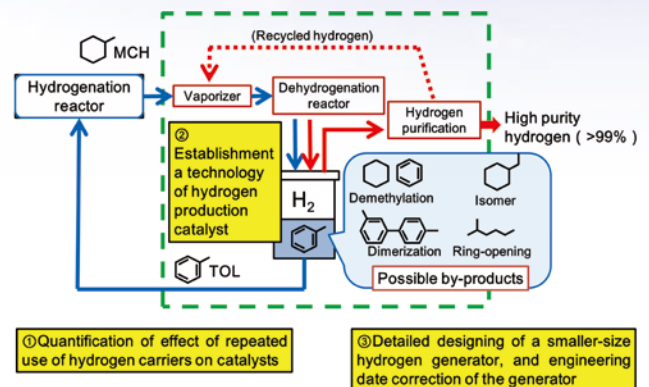


Fig.1: Hydrogenation and dehydrogenation cycle of MCH

② Unified Demonstration System of Hydrogen Energy Carrier Production/Utilization

The world largest class hydrogen energy carrier production and utilization system was launched. This system integrates large scale alkaline water electrolyzer, catalytic hydrogenation reactor, large storage tanks, and co-generation engine with catalytic dehydrogenation reactor. 5MWh of electricity (Equivalent to 500 days of ordinary home electricity consumption) has been stored by hydrogen or MCH in the last one year. This system will be combined into the energy network in FREAA to suggest a strategy for electricity storage and utilization.

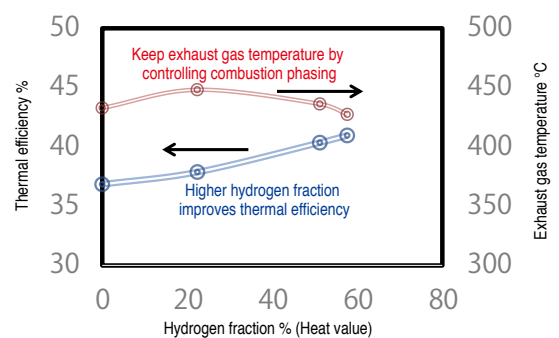


Fig.2: Thermal efficiency and exhaust gas temperature as a function of the hydrogen ratio of the next-generation cogeneration engine

③ Advanced Co-generation Engine by use of MCH (Fig.2)

The team is conducting research and development for the next-generation cogeneration engine with a dehydrogenation catalytic reactor of MCH which can recover engine exhaust heat. Also a dual fuel engine combustion technology of diesel and reformed hydrogen from MCH is being developed. The world's best hydrogen generation from MCH is realized by enhancing the recovery of heat such as the elevated temperature of engine exhaust heat. In terms of an engine combustion technology with hydrogen, 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.

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

For combustion use of ammonia, micro gas turbine (rated power: 50kW) combustion has been challenged, and 41.8kW power generation was successfully achieved by methane-ammonia gas and 100% ammonia. These are world's first research results.

This research and development is conducted under the Cross-ministerial Strategic Innovation Promotion Program (SIP) "Energy Carrier" of the Cabinet Office (management corporation: JST).

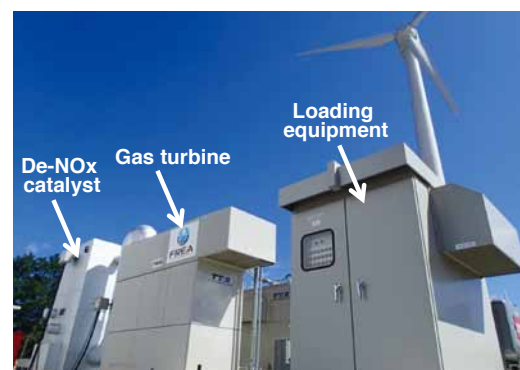


Fig.3: Ammonia Gas Turbine

Wind Power Team



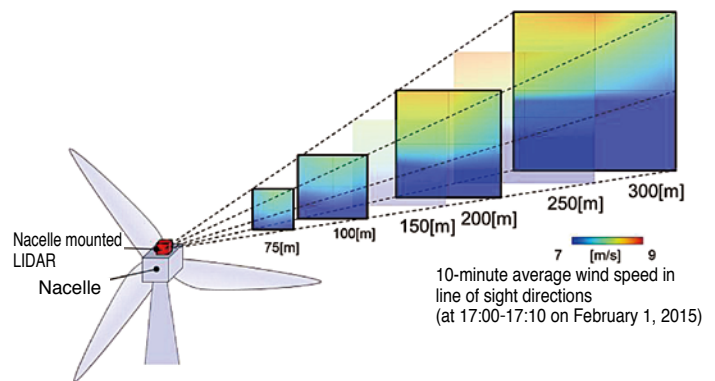
— Advanced Technology for Wind Power Generation —

Although the practical application of wind power generation has progressed, the further reduction of power generation costs is required to accelerate its further promotion and to achieve grid parity. To do so, the software aspects of advancement is necessary such as the prior selection of suitable sites, the assessment of annual energy production, and forecasting techniques during operations in addition to the hardware's sophistication of wind turbines.

Research Target

The team aims to establish elemental technologies for high performance wind turbines and their assessment techniques toward the further reduction of power generation costs and to contribute to the sound promotion of the domestic introduction amount and the improvement of the international competitiveness of wind power industry in Japan by placing such advanced technologies into practical use together with the domestic wind power industries.

- ①The team set a goal of improving power generation amounts by +5% or more and the lifetime of wind turbines by +5%-10% or more by developing and demonstrating elemental technologies for sophisticating performance of single wind turbine and the entire windfarms.
- ②The team set a goal of errors of $\pm 5\%$ or less as well as the reduction of measurement and assessment costs by 20%-30% by achieving the sophistication of assessment technologies for wind power generation.



An example of measured result by a nacelle mounted LIDAR installed on a research wind turbine (distribution of wind speed in line of sight directions)

※LIDAR: Laser Imaging Detection and Ranging
(a device for the remotely measuring wind speed and wind direction by laser light)

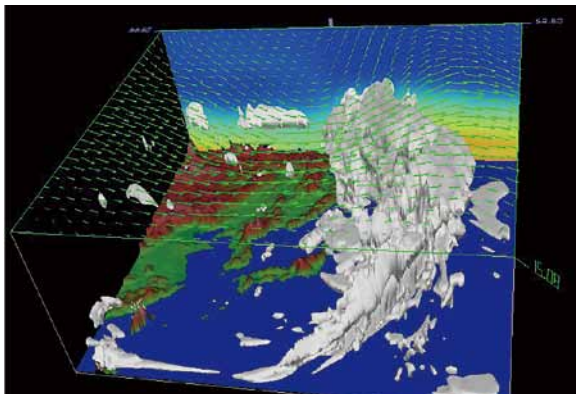
Research Outline

①Elemental technologies for a high-performance wind turbine

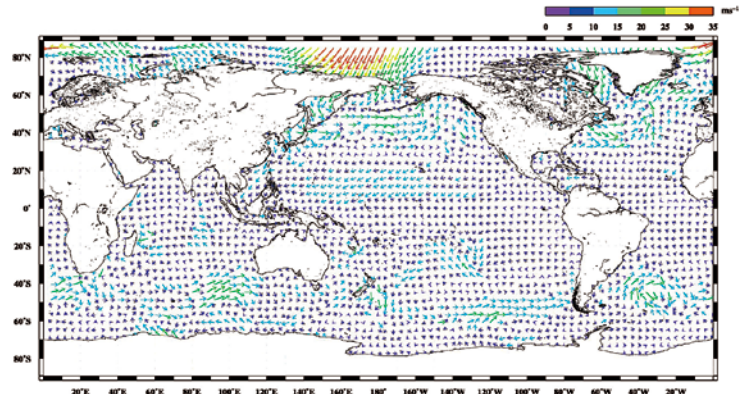
Focusing on a nacelle mounted LIDAR as a new promising technology for measuring the wind speed and direction in the upstream side of a wind turbine, the team will develop and demonstrate a high-performance prototype of nacelle mounted LIDAR. This technology can improve the wind turbine's power output by performing the feed-forward control (yaw control and pitch control) of the wind turbine based on the information on wind velocity in the upstream side of a wind turbine obtained through a nacelle mounted LIDAR, and it can also improve the reliability and the lifetime of a wind turbine by reducing the load on wind turbine blades. The team is promoting basic studies and empirical research on them.

②Sophistication of wind turbine generation assessment technologies

It is indicated that the wind measurements with a meteorological mast at the offshore site is very difficult economically, except for national research and demonstration projects. As a new alternative technology to high-cost in-situ measurements at the offshore site, the team is developing a technology for evaluation and prediction of offshore wind with the use of satellite remote sensing and a numerical meteorological model. Cost reduction (to several hundred million yen (1/5-1/10) or less) is expected by this alternative technology using a numerical meteorological model and satellite remote sensing.



Numerical meteorological model



Satellite remote sensing

Main Research Facilities



A prototype of nacelle mounted LIDAR manufactured by a domestic manufacturer

(The photograph taken with an operation-state monitoring camera on a nacelle)
It is a device that allows the measurement and assessment of wind speeds and directions on the upstream side of a wind turbine by irradiating laser light in front of a wind turbine (in nine directions).



Research wind turbine

Komaihaltec, Inc. KWT300
Rated power output: 300 kW, rotor diameter: 33 m, and hub height: 41.5 m

A wind turbine is designed to withstand severe external conditions in Japan (highly turbulent flow arising from the complex terrains, etc.). AIST also make cooperation and contributions through joint studies at the design stage.



Ground based LIDAR
It is a device that remotely measures the wind velocities at a height of 50-200 m above the ground.



Satellite and meteorological data processing system
It is a computer system for providing a storage of about 1 PB (petabyte), which stores large-scale satellite and meteorological data and processes these data.



Search device for acoustic source
It is a measurement system that allows surveys of acoustic sources; it comprises 30 acoustic Microphone and transducers.

Recent Activities and Achievements

① Field demonstration results of the nacelle mounted LIDAR (Fig. 1)

The team succeeded in remotely measuring the wind speed distribution in the upstream side of a wind turbine with a high-performance nacelle mounted LIDAR. The team found that wind energy could be increased by about 6% at the maximum by reducing the appearance frequency of a yaw error larger than $\pm 10^\circ$ based on the information about the wind direction in front of a 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 a 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 developed the high-resolution sea-surface temperature dataset of Modis-based Sea Surface Temperature (MOSST) (Shimada 2015), which resulted in the significant improvement of the reproducibility of atmospheric stability near the sea surface.

③ Advanced assessment technology (Satellite remote sensing) (Fig. 3)

The team developed a method for sea surface wind speed retrievals with the use of a satellite-borne Synthetic Aperture Radar (SAR) in consideration of the atmospheric stability. Moreover it is clarified that relations between fetches and retrieval errors when offshore winds blow are remarkably different from those when onshore wind blow because of a land effect.

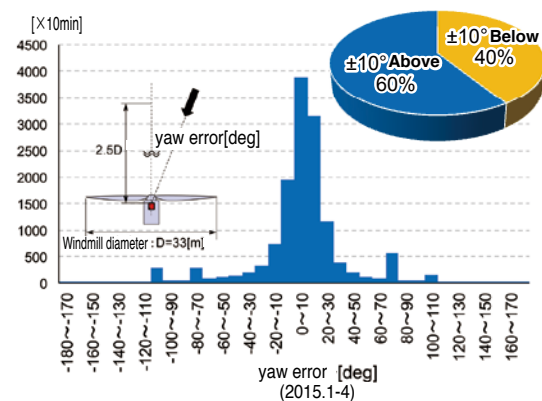


Fig. 1 Histogram of the yaw error (an error in the wind turbine direction against the inflow wind direction)

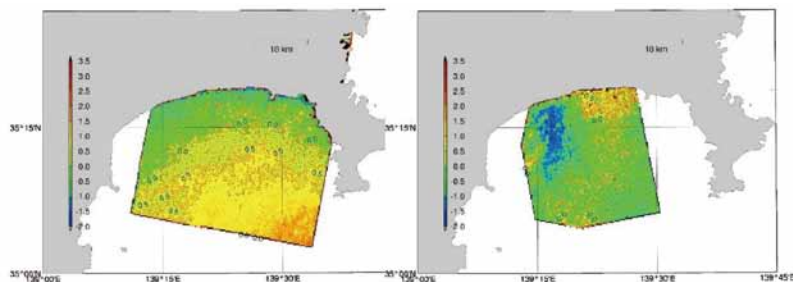


Fig. 3 The difference between a measured value on an ocean observation tower (1 km offshore) and a predicted SAR wind velocity (Hiratsuka)

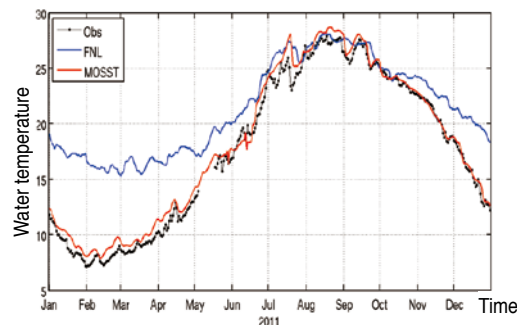


Fig. 2 Comparison between various sea surface temperature datasets and measured data (Osaka Bay)

Photovoltaic Power Team



— High-Performance PV Modules with Thin Crystalline Silicon Solar Cells —

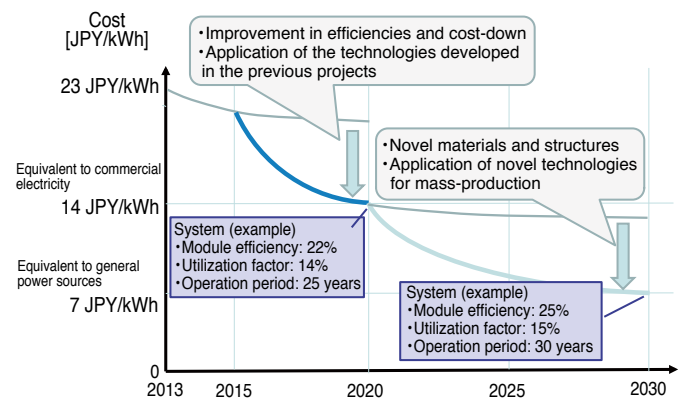
A large number of photovoltaic (PV) systems have been installed under Feed-In Tariff (FIT) since July 2012. In addition to the conventional installation on house rooftops, many large-scale power plants so called “mega solar” have been constructed. Reduction in PV power generation cost is very important to reduce the burden share of 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 focusing on the research of “smart stack technology” to develop a next-generation highly efficient solar cells (conversion efficiency higher than 30%). The technologies to achieve the power generation cost target of 14 JPY/kWh in 2020 and 7 JPY /kWh by 2030 will be developed.



Japanese PV roadmap for 2030 (NEDO PV challenges)

Research Outline

Though the crystalline silicon (c-Si) technology dominates the share in the PV-market, it requires significant cost reduction 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 thicknesses of about 0.10 mm (from the present cell thickness of 0.18 mm to 0.08–0.10 mm).

The team also investigates the relationship between the cracks and the wafer strength to develop thin and tough wafers and to improve the yield during the cell processes such as the wafer cleaning.

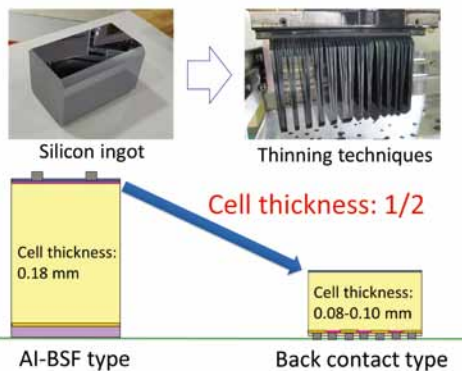


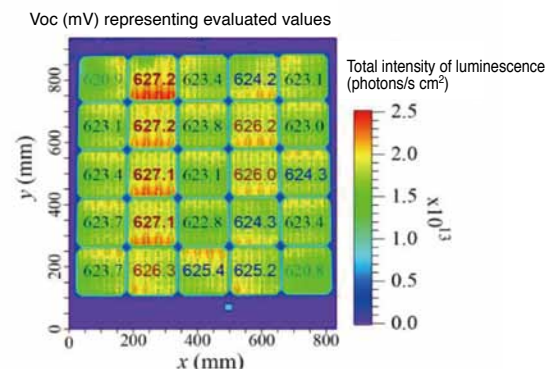
Figure of thinning process of wafer (cell)

● 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 the ion implantation can make possible the reduction of the number of cell processes during the back-contact cell fabrication.

● Improvement in module reliability and development of a new evaluation method

A new nondestructive module evaluation method through the 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 from the luminescence intensity of the cells, and this technique is nondestructive.

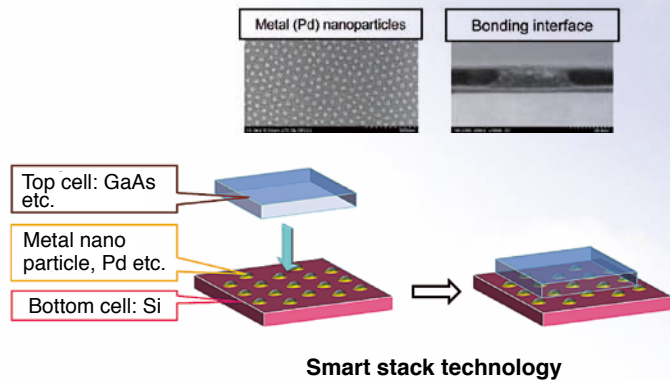


Voltage mapping by the absolute electroluminescence method

●Next-generation multijunction solar cell “smart stack technology”

The “smart stack technology” using metal nanoparticle arrays has been developed, for the first time, making possible the interconnection of various solar cells based on different materials and bandgaps. It can provide the flexibility in material choice and device design because the mismatch in lattice constants, thermal expansion coefficients, etc., can be neglected in this technique.

A GaAs/InP-based four-junction solar cell has achieved a conversion efficiency of as high as 31.6%, and a GaAs/CIGS-based three-junction solar cell has achieved a conversion efficiency of as high as 24.2% (joint



research with the Research Center for Photovoltaics at AIST Tsukuba Center). We are aiming 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 multijunction cells. The team is developing the crystalline silicon based smart stack cells that goes beyond the theoretical limit efficiency of single junction crystalline silicon solar cells. The mechanical stacking based on Pd nanoparticle was found to be stable and electrically conductive and optically transparent in the GaAs/Si two-junction cells.



Main Research Facilities



Electrode firing furnace

A furnace for forming contacts between the electrode and the diffusion layer as well as Al-BSF layers



Spin etching apparatus

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

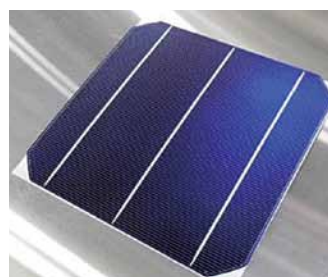


Ion implantation equipment

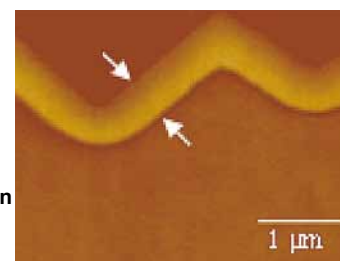
An equipment which implants accelerated phosphorus or boron ions into the wafer. The diffusion profile can be precisely controlled

Recent Activities and Achievements

- ①The facilities for crystalline Si solar cell and module fabrication have been installed and started operation. The FREA standard cells with Al-BSF have been fabricated with an average cell efficiency of about 19.3% equivalent to the best reported efficiencies from mass-production
- ②The thin wafer (0.12 mm thick) slicing technique from silicon ingots has been established using diamond wires. The processing conditions close to the mass production of the wafer with the thickness of 0.12 mm have been established with a 99.8% yield.
- ③The smart stack technology was applied to a GaAs/InP-based four-junction cell to achieve a conversion efficiency of as high as 31.6%.
- ④0.1 mm-thick double-sided solar cells have been fabricated.
- ⑤A diffusion layer with a uniform depth on pyramid-shape surfaces has been formed successfully by means of ion implantation, demonstrating cell efficiencies of as high as 18.7%.
- ⑥A new module evaluation technique was developed (absolute EL method, an in-situ AC impedance measurement method). The place of failure can be identified nondestructively, and the voltage of each cell within a module can be evaluated individually.



Outlook of a crystalline silicon cell by standard FREA process



Phosphorus diffusion layer formed by the ion implantation

Geothermal Energy Team

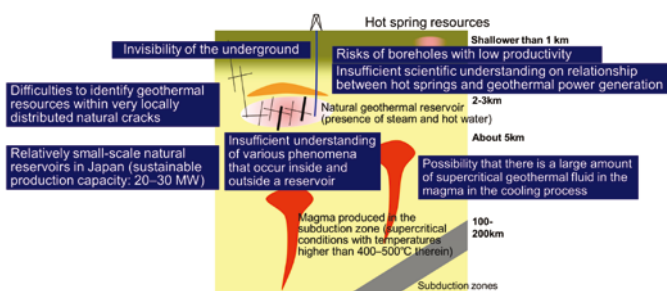


– Technologies for the Effective and Sustainable Use of Geothermal Resources –

Japan as a volcanic country is located on a subduction zone of an oceanic plate, where there is a vast amount of geothermal energy. Since geothermal energy is stable, not dependent on time and weather conditions, etc., it is expected to play a role as a base load energy source among renewable energy.

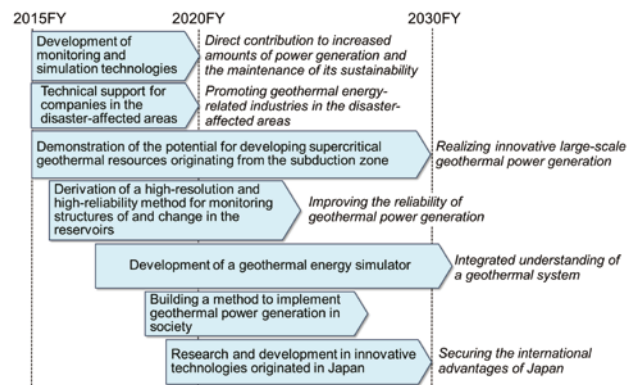
Research Target

The team is conducting research and development to sustainably utilize geothermal energy on a suitable scale and in a proper style conforming to underground conditions and social situations with the following keyword: "Proper use of geothermal energy." In the short term, the team is aiming to make direct contributions to the sustainable power generation and the increase in its amount through the development of monitoring system for coexistence of geothermal power generation with hot springs and the advanced monitoring of the change in the reservoirs.



A need for studying and developing geothermal energy

In the long term, furthermore, 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 derivation of a method for the social implementation of geothermal energy.



Road map

Research Outline

To date, 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 various basic studies in geosciences to improve the scientific understanding of geothermal systems. Since the underground is invisible and since the properties of the geothermal resources largely depend on the specific areas, it is very important to acquire actual data in the field and conduct studies based on them in 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 Micro Electro Mechanical Systems (MEMS), optical fibers, etc. and by deriving advanced analysis technologies such as transient multicomponent signal processing and the integrated interpretation method.
- Compiling huge amounts of geothermal resource information possessed by AIST into an advanced database, presenting optimal development methods, and achieving the coexistence with hot springs by developing a geothermal energy simulator.
- Developing an optimal creation and control technology of a reservoir using hydraulic stimulation and fluid injection. This allows the derivation of a universal development and utilization method.
- Exploring the possibility of exploiting supercritical geothermal resources

originating from the subduction zone and making it available for large-scale base-load power generation in 2040.

The team proposed the possibility of generating several 10 GW-several 100 GW power by exploiting a supercritical geothermal resource originating from the subduction zone. The team is drawing out a research plan to make this geothermal resource available as a base-load power source in 2040.

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

Concept of a supercritical geothermal system

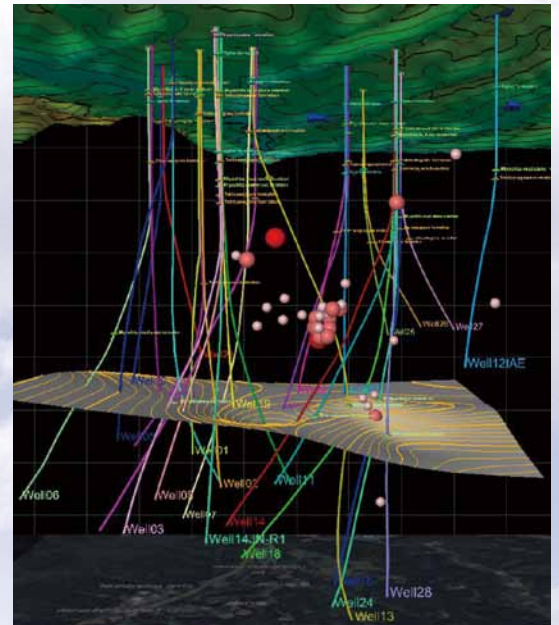
Distribution of old caldera (Oyagi, 2003)



Yanaizu-Nishiyama Geothermal Power Plant
(Source: Tohoku Electric Power Co., Inc.)



Status of installing the downhole three-component seismometers



Micro-earthquake data integration and visualization system
(monitoring the behavior of the injected water)

A water-recharge injection test to prevent a decrease in steam production and recover production is being conducted at the Yanaizu–Nishiyama Geothermal Power Plant in the Fukushima prefecture since FY2015. In this area, the geothermal energy team installed a high-density micro-earthquake remote monitoring network using three-component geothermal well seismometers and other equipment, and operations were commenced. This enables the real-time monitoring of the micro-earthquake activities and advanced integrated analysis in FREA, and our plan is to contribute to the production recovery by proper water injection.

Main Research Facilities



Simulated hot spring water generator

Hot spring water of various spring qualities can be simulated. Used for the evaluation of a hot spring monitoring sensor, experimentation of a hot spring power generator, etc.



Downhole three-component seismometer for a geothermal well

It is a downhole tool that can detect extremely small earthquake motions occurring inside and outside the geothermal reservoir developed by AIST.



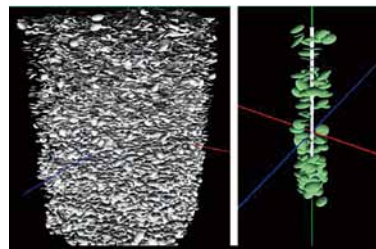
Multiplexing sensing instrument for optical MEMS sensor

The team developed a device enabling the measurement of earthquake motion at many points with many optical MEMS sensors fabricated on an optical fiber.

Recent Activities and Achievements

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

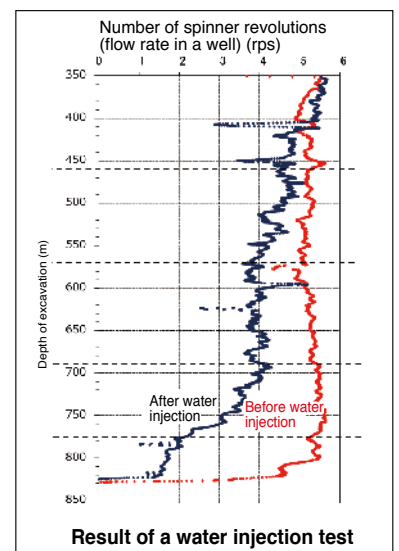
In some case, the capacity of a geothermal reservoir is improved by water injection to the reservoir through a geothermal well. The geothermal energy team cooperated with US and European researchers to develop a simulator for simulating the response of a crack to water injection. As a result of conducting a demonstration test on a well with the reduced capacity in a geothermal field of the Tohoku region, the team achieved the capacity improvement as predicted from the prior 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 monitoring system of a hot spring's quality

The team began to develop a system enabling the measurement of spring qualities of the hot springs' temperature, flow rate, electric conductivity, etc., producing a prototype to scientifically explain the relationship between the geothermal power generation and the hot springs. This system enables stand-alone measurements and continuously transfers the obtained data to a server through the Internet. In the future, the team will continue performance evaluations using the simulated hot spring water production device and field demonstration tests for practical application at the end of FY2017.



Result of a water injection test

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 was originally spread in western countries in the 1980s after the world oil crisis in 1970s. Although it is not new technologically, its spread has been delayed for it was hardly known in Japan until about the year 2000. Restriction on groundwater use in big cities is another reason of its delay especially for open loop systems. Because the existence of groundwater and its flow rate largely affects the heat exchange rate, it is important to understand water level and flow rate of groundwater systems in order to utilize GSHP in Japan effectively.

Research Target

GSHP system is highly efficient and energy-saving compared to normal air conditioners (air-source heat pump systems). The team will promote GSHP system by enhancing its performance and lowering its cost on the basis of geological information.

There are two types of GSHP system: 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 water level and flow-rate of the groundwater. Japanese way of research on GSHP considering groundwater system may be applied and may bring advantages for Southeast Asian countries. We,

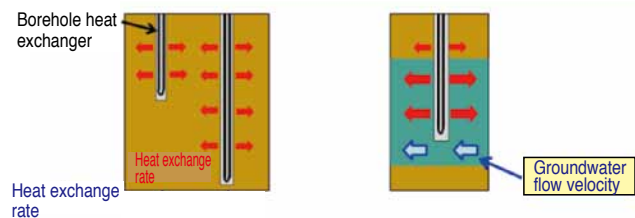
therefore, are engaged in the following research targets to develop GSHP systems suitable for the hydro-geological characteristics of the site:

- GSHP suitability mapping based on field data collection and schematic model construction,
- Conceptual designing on the optimization technology of a GSHP system and
- Expansion of GSHP studies in Southeast Asia and in other regions, etc.

※COP: Coefficient of Performance

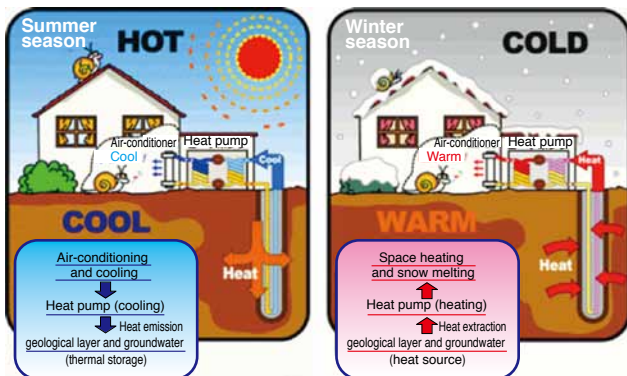
The suitability of GSHP depends on the heat exchange rate, the potential of total heat exchange, and groundwater characteristics

Geology, groundwater level, velocity of groundwater flow, subsurface temperature, water quality, etc.



Suitability assessment technologies for ground-source heat pump application

The idea of suitability map for ground-source heat pump (GSHP) systems considering effects of groundwater is new invention of AIST.



Outline of a ground source heat pump system

Research Outline

To use GSHP, it is important to understand the subsurface hydro-geological condition of the site. We, therefore, conduct boring geological survey, groundwater temperature survey by depth, regional heat transport simulation with advection effect of groundwater flow, etc., to investigate 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 various different subsurface conditions. At a GSHP demonstration test site of FREA, the team conducts experiments with two types of heat exchangers: shallow (horizontal) and deep (vertical) ones. The same 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 hydro-geological settings.

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

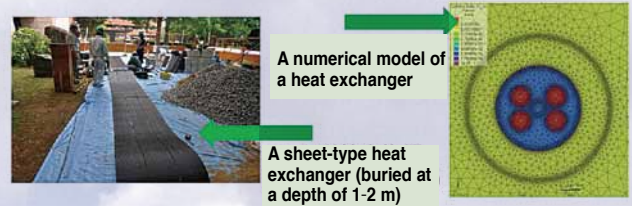
● Research on GSHP suitability assessment

In Japan there are many regions where groundwater is so abundant at a depth of several meters to 100 m, that utilization of GSHP system should be more efficient if flow property of groundwater is considered. In order to promote appropriate GSHP system utilization, the team conduct research and studies in collaboration with the Geological Survey of Japan of AIST. The team is also developing methods to assess suitability of different GSHP systems based on field surveys and numerical analyses.

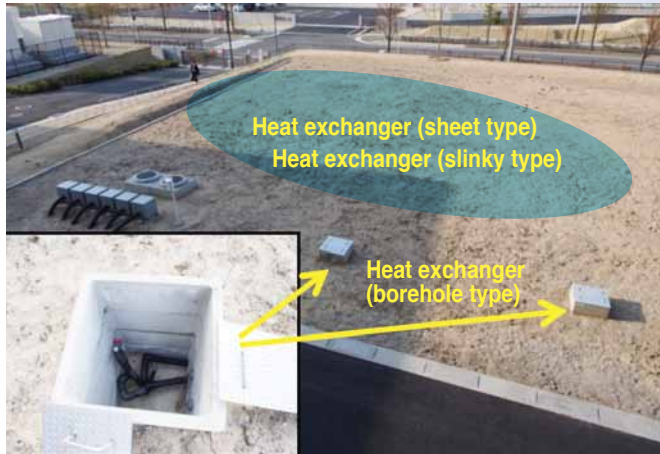
●Technology development for GSHP systems optimization

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

of heat exchange borehole, the team aims to promote and diffuse GSHP system.



Main Research Facilities



FREA Ground-Source Heat Pump System Demonstration Area
 This is a GSHP system using 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 to a depth of about 40 m



A ground source heat pump (GSHP) system installed at the Chulalongkorn University, Thailand
 A facility at the Chulalongkorn University in Thailand was used to demonstrate the possibility of cooling operation through the GSHP system in Bangkok.
 *GSHP: Ground Source Heat Pump

Recent Activities and Achievements

①GSHP suitability evaluation of the Tsugaru Plain

The team constructed a groundwater-flow and heat-transport model with the result of the incorporated thermal response test (TRT) [Fig. 1]. The team estimated effective thermal conductivity distribution based on the results of flow simulation and TRT, and overlapped the effective thermal conductivity on a subsurface temperature distribution map with Geographic Information System (GIS) to invent a totally new suitability map (for heating) [Fig. 2]. Combining the existing observation well data with the results of the TRT, a high-precision map could be created from few observation well data (original technology of AIST).

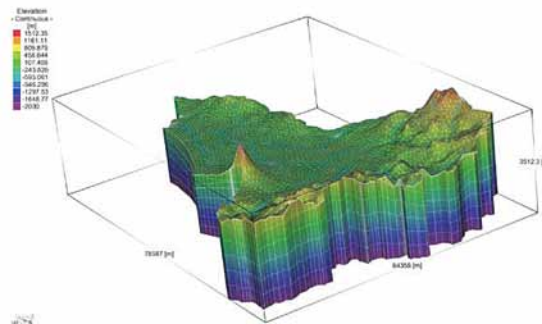


Fig. 1: Three-dimensional groundwater-flow and heat-transport model of the Tsugaru Plain

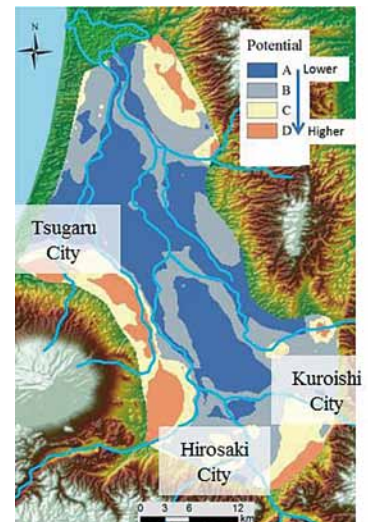


Fig. 2: A new suitability map

②Analysis of hydro-geological structure of the Aizu Basin

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

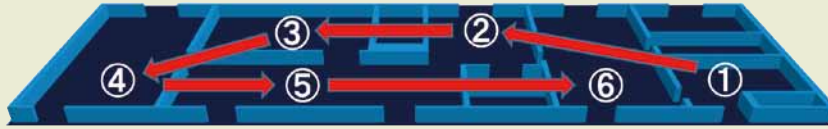
③Performance evaluation of a closed-loop GSHP air-conditioning system using an artesian well

The team constructed a closed-loop GSHP system using an artesian well by a joint research project with Japan Ground Water Development Co., Ltd. through “Program for Promoting Technologies Invented by Industry in Disaster Areas in Tohoku.” The team built a system to control the natural flow by the well temperature. COP greater than seven in the cooling operation and COP greater than five in the heating operation were observed, which depends on the operating condition, though.

Main Demonstration Facility

Thin-Crystalline Silicon Solar Cells R&D Foundry

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



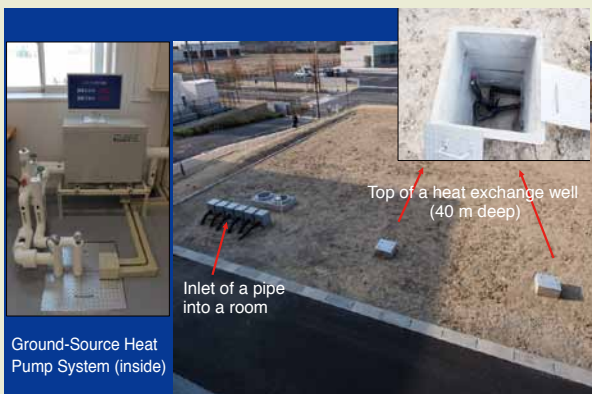
Thin-Crystalline Silicon Solar Cells R&D Foundry Layout Chart

<p>① Silicon Ingot Slicing (Wafering)</p>  <p>Multi-Wire Saw</p>	<p>② Surface Texture Formation</p>  <p>Surface Texture Formation Machines</p>	<p>③ PN Junction Formation</p>  <p>Thermal Diffusion Apparatus Ion Implantation Machine</p>
<p>④ Antireflection Film Deposition</p>  <p>PE-CVD Machine</p>	<p>⑤ Electrode Printing and Firing</p>  <p>Electrode Printing and Firing Machine</p>	<p>⑥ Photovoltaic Module Fabrication and Reliability Test</p>  <p>Vacuum Laminator Reliability Test Machines</p>

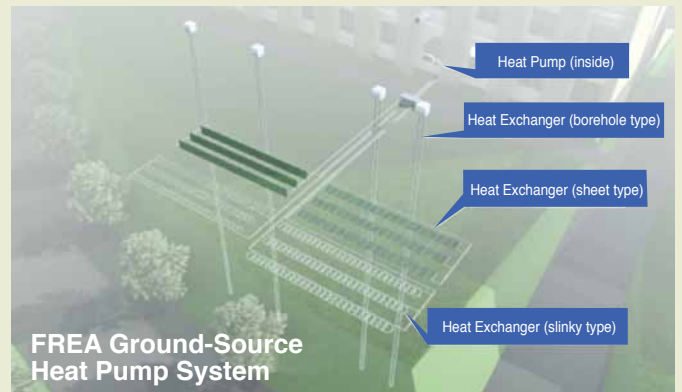
Ground-Source Heat Pump System Demonstration Area

At the demonstration test site for the geothermal heat utilization system at FREA, GSHP systems is installed using a sheet-type and a Slinky-type heat exchanger installed at a depth of 1-2 m underground and a vertical-type (borehole type) heat exchanger installed at a depth of about 40 m. The team compares these systems and develops a technology for optimizing operating methods combining both of them.

A real-time monitor is also installed to display the underground temperature, the COP (performance indicator) of the system, the 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 the portion of heat exchange wells.



Overview of Ground-Source Heat Pump System Demonstration Area



State of installation of an underground heat exchanger

Demonstration Field



Aerial View of Demonstration Field

① Energy Control Building

The team is conducting studies on a renewable energy network through the combination of large-scale PV and wind powersystems with power storage with hydrogen and batteries.

[Characteristics]

- Power grid simulator (AC simulator: 500 kVA)
- Solar photovoltaic array simulator (600 kW)
- RLC load (250 kVA)
- PV power conditioning system (three types, one piece for each type)
- Solar simulator for a solar-cell 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-largest MCH manufacturing and utilization demonstration equipments with large-scale alkaline water electrolysis, a hydrogenation catalytic reactor, a large storage tank, and a dehydrogenation catalytic reactor equipped cogeneration engine integrated is operated to demonstrate a hydrogen energy carrier manufacturing and utilization integration system.

[Characteristics]

- Hydrogen generation capability by alkaline water electrolysis: 34 Nm³/h
- Hydrogenation catalyst: 70 L/h (MCH manufacturing capability)
- 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

The team is conducting researches on hydrogen energy storage systems and thermal energy storage systems.

[Characteristics]

- Solid polymer-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

The team is 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 pieces)
- Area of demonstrating the PV generation system is about 8,000 m²

⑤ Wind Power Generation System

The team is conducting the verification of the Japanese-type wind turbine design criteria and the demonstration study on an advanced wind turbine control technology. A LIDAR equipped with a nacelle is used to develop and evaluate technologies and devices to remotely measure the wind's velocity and direction in the upstream side of the wind turbine from above the nacelle. In addition, the team measures and assesses the wind turbine noise with a sound-source surveying device to elucidate the noise properties and also conduct studies on noise reduction.

[Characteristics]

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

⑥ Ammonia Direct Combustion Gas Turbine Demonstration Facility

The team is conducting research and development on a gas turbine power generation technology 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 succeeded in the gas turbine power generation of 41.8kW by using methane-ammonia mixed gas. Moreover, 41.8kW power generation 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 conformed sufficiently to the environmental criteria.

“Smart System Research Facility”, Cutting-edge Research, Development, and Certification for Large DER Systems

The world's top-level test evaluation and research development facilities (Smart System Research Facility) of cutting-edge power electronics equipment are being prepared, such as large PCS essential for the introduction of renewable energy.

It will become a user facility for the performance test of distributed power supplies and the performance verification of an EMS that integrates distributed power supplies on an actual scale.

By cooperating with international research institutes, the team aims at the international standardization and the international certification of the products.

The following four kinds of test equipment will be installed at the facilities:



Smart System Research Facility (April 2016: expected opening)

1. System interconnection test equipment

It is the equipment where tests required for power quality assurance in interconnections of distributed power supplies with a power system and advanced tests of PCS (islanding operation prevention test, FRT test, etc.) are conducted. The maximum capacity of the grid simulator is 5 MVA, and the maximum capacity of EUT is 3 MW.

2. Safety test equipment (a temperature controlled room, etc.)

It is the equipment where high-temperature acceleration tests and heat-cycle tests are conducted by simulating the actual environment on PCS, and then, safety tests such as long-term reliability evaluations and surge (momentary abnormal high-voltage) tests are conducted.

3. Electromagnetic environment compatibility (EMC) test equipment (an anechoic chamber)

It is the equipment where tests such as the measurement of electromagnetic radiation (interfering wave) from PCS and the determination of whether the function and operation of PCS are obstructed by external electromagnetic noise are conducted.

4. System performance test equipment

It is the equipment where distributed power supplies (solar power generation, batteries, etc.) and PCS are integrated in a single system to evaluate various performances (such as automatic control performance with weather).

Collaboration

AIST, as one of the largest public research institute in Japan plays a central role in cooperating with the industry, the academia, and the government as the world's innovation hub by utilizing and developing diverse research personnel, advanced research infrastructures, research results, mechanisms of technology fusion and human resource development, local bases and their networks, etc. The team presents examples of collaboration activities with companies in disaster-affected areas, local universities, etc. below.

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

AIST conducts the “Program for Promoting Technologies Invented by Industry in Disaster Areas in Tohoku” from FY2013 as the program wherein the Institute provides technical support for the seeds (producer-driven solutions) related to renewable energy that the companies in disaster-affected areas (three prefectures: Fukushima, Miyagi, and Iwate Prefectures) that underwent tremendous damages in the Great East Japan Earthquake.

The Institute has supported a total of 63 cases (33 companies) so far, two of which (“solar cell string monitoring system” and “bypass diode checker” in the right figure) succeeded in practical application as a new project, whereas five of which are starting to provide specific outcomes such as the state close to their practical application.

●Renewable energy field through the joint research with the institute

The Institute accepts students from local universities (College of Engineering of Nihon University, Fukushima University, University of Aizu, Tohoku University, and others) from the FY2014 and implements a training project for industrial human resources in the renewable energy field through the joint research with the institute.



String monitor [Neoale] manufactured by Asahi Denshi Co., Ltd.

Solar cell string monitoring system

It is a device that measures current and voltage of a solar module. This was manufactured as a monitoring and generated power recovery device for a PV generation plant in support of AIST.



Bypass Diode Checker manufactured by Nippon Kernel System Co., LTD

Bypass Diode Checker

Bypass Diode Checker has been commercialized with the AIST's technical support as a device that can detect open failure of bypass of the photovoltaic module. To avoid impact on photovoltaic power generation, inspection of the bypass circuit will be carried out during the night. This device will contribute to enhance the soundness and safety of photovoltaic power system.

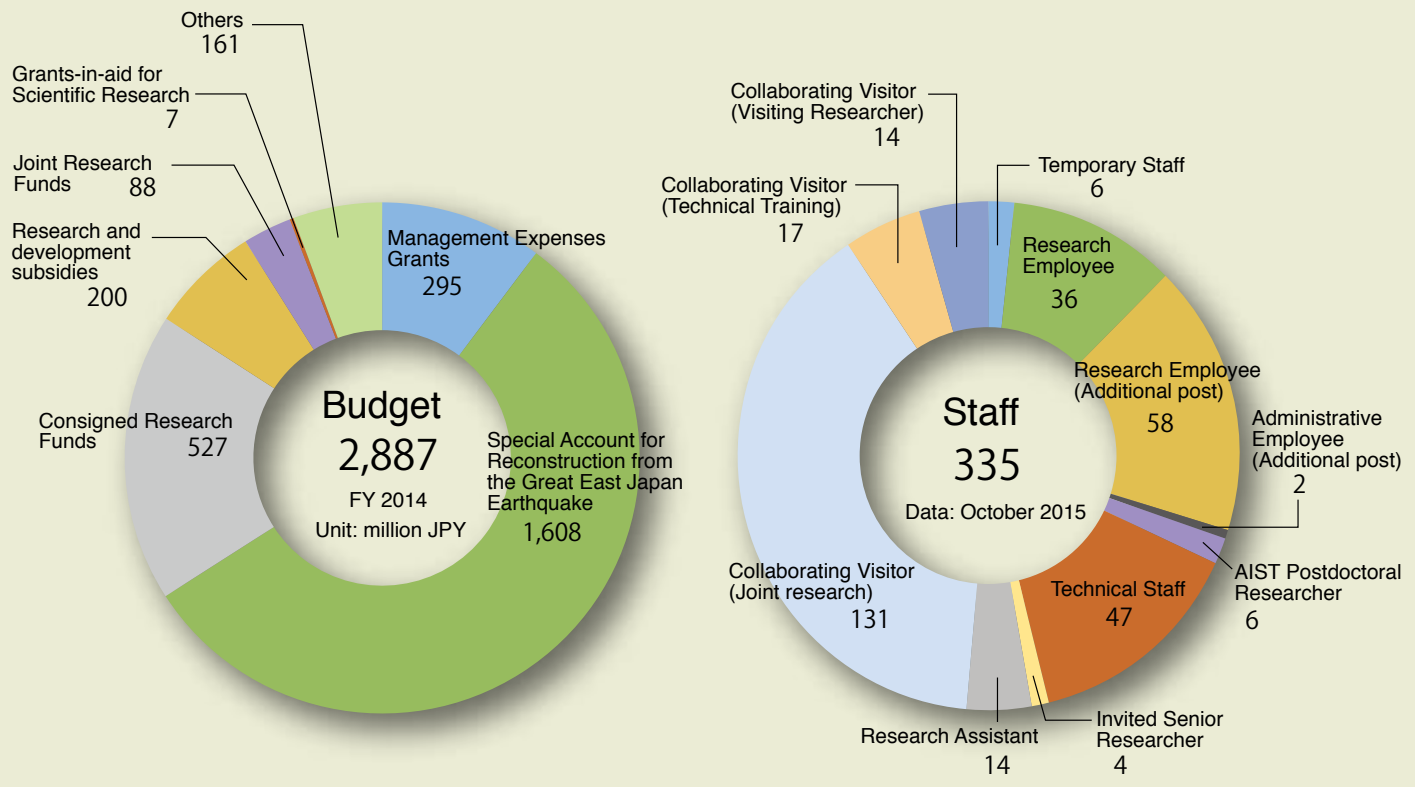
Joint research of RENRC promoting (as of September 2015)

●“Program for Promoting Technologies Invented by Industry in Disaster Areas in Tohoku”	25
●Joint research with local universities:	17
●Joint research with companies:	35
●Other joint research:	6
Total number	83

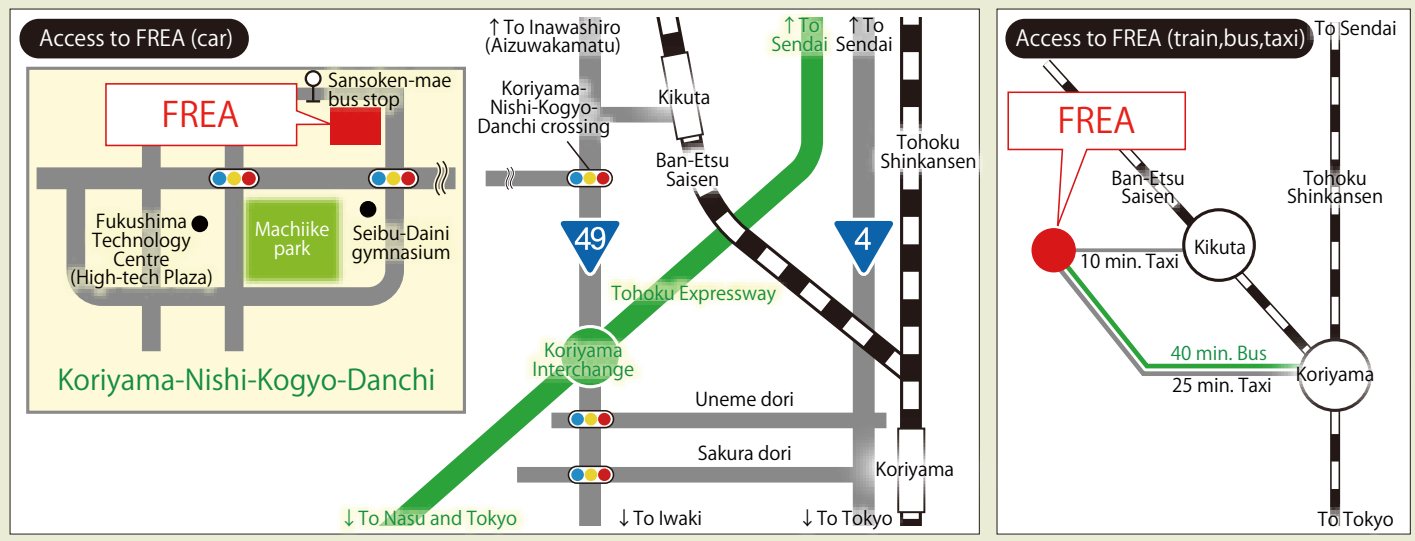
Main upbringing human resources (employment results in fiscal year 2014)

●AIST Postdoctoral Researcher	7
●Research Assistant	12
●Internship	5
●Technical Staff	27
Total number	51

Budget and Staff



Access



International Activities

AIST has been actively developing international partnerships with overseas research institutes since its foundation in 2001 through the various cooperation scheme such as memorandum of understanding on comprehensive research cooperation (MOU), letter of intent (LOI), etc. We also welcome long- and short-term visiting researchers and guests from overseas research organizations. Please visit the following website for details.

Details

http://www.aist.go.jp/aist_e/international/



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