Renewable Energy
Research Center (RENRC)

AIST
NATIONAL INSTITUTE OF
ADVANCED INDUSTRIAL SCIENCE AND TECHNOLOGY (AIST)

FREA
FUKUSHIMA RENEWABLE ENERGY INSTITUTE, AIST

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Japan's energy self-sufficiency ratio has dropped significantly to about 6% and the energy-oriented CO_2 emission became highest ever after the Great East Japan Earthquake in March 2011. The issues on energy mix have been discussed extensively, and the policy goal of improving the energy self-sufficiency ratio, cutting down the electricity cost, and significantly reducing CO_2 emission has been set. The new energy policy aims the maximum introduction of renewable energy with reduced costs.

Deployment of renewable energies can contribute to improve the energy self-sufficiency ratio as well as to reduce the CO_2-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 (FREA) 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 engaged in R&D of renewable energy technologies in FREA. RENRC consists of six research teams (Photovoltaic Power, Wind Power, Hydrogen Carrier, Geothermal, Shallow Geothermal and Hydrogeology, and Energy Network) with 37 full-time staff members (as of April 2016) and a research budget of about 2.9 billion JPY (FY2015).
RENRC runs the following research topics aiming for the high penetration and sustainable-growth of renewable energy.

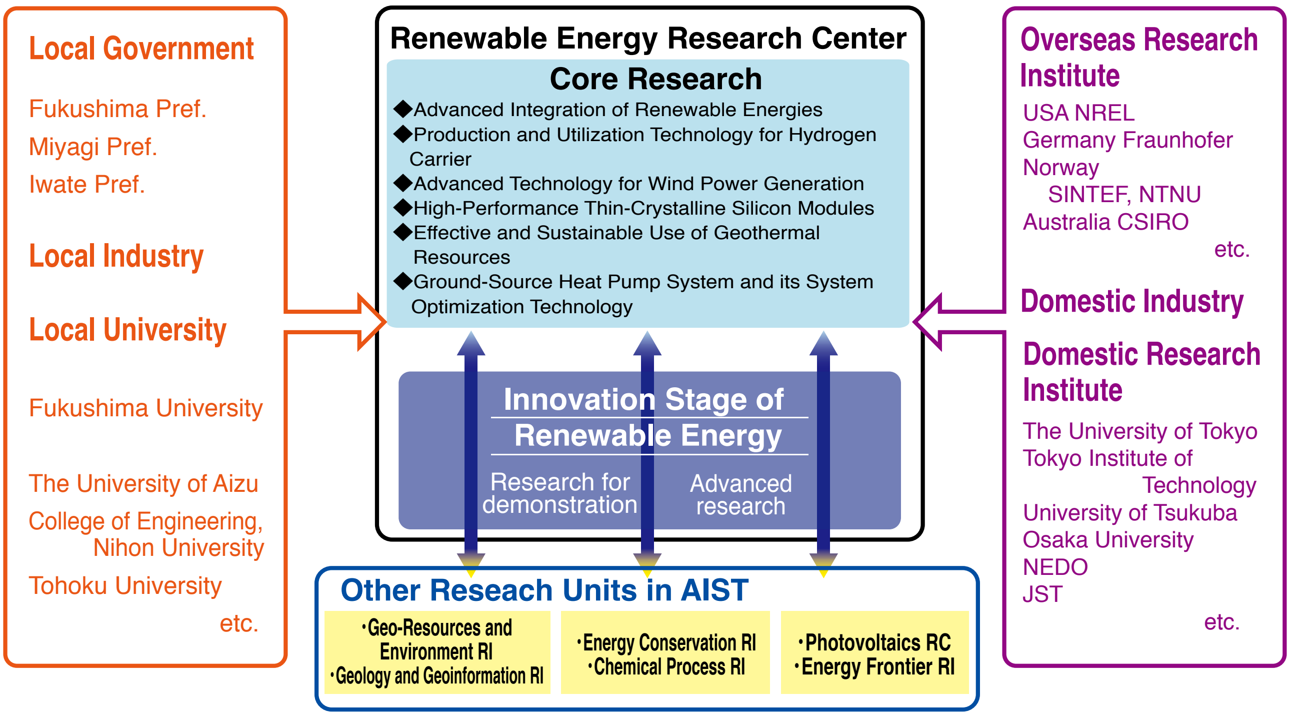
- Make breakthroughs in each renewable energy technology and develop smart system integration techniques
- Significant reduction of power generation costs and improvement in utilization efficiencies of PV power generation system.
- Develop the technologies for appropriate use of geothermal resources 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; the 59 concurrent AIST researchers from other regional research centers and 3 university professors through the cross appointment system.

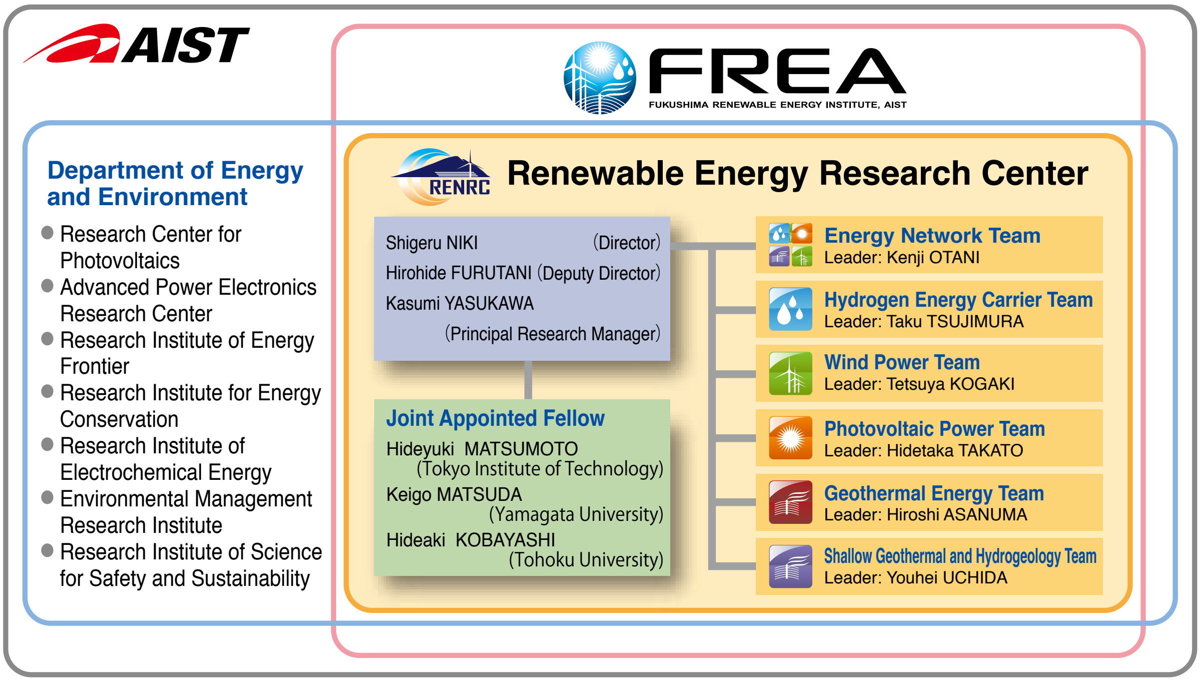
As an international innovation hub of renewable energy, we promote the collaborations with domestic and international research organizations, and contribute to the development of the industrial clustering and human resources.

Renewable Energy Research Initiative



RI:Research Institute　RC:Research Center

Organization Chart



Energy Network Team

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

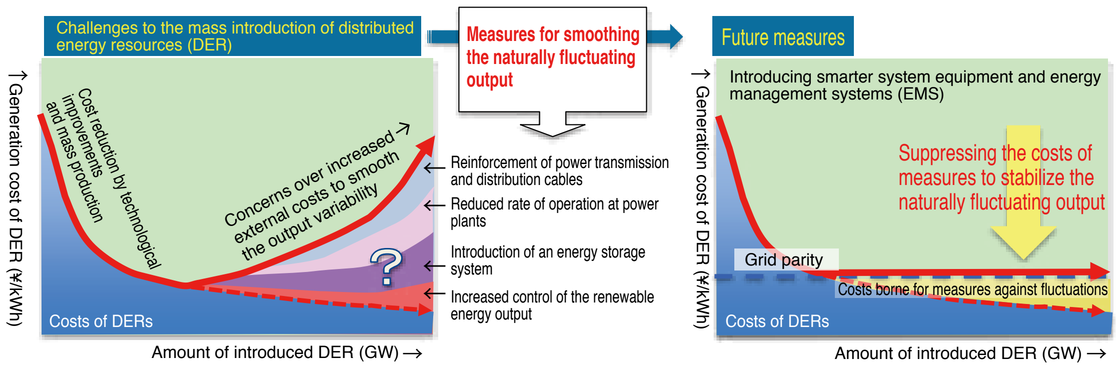
To realize high penetration of distributed energy resources (DERs) into energy networks, adjusting the simultaneous balance of intermittent DER supply and energy demand is essential by using existing power plants and energy storage systems. The combination of appropriate DER according to each location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

Research Target

To reduce consumption of exhaustible energy resources (fossil fuel and others) and the CO_2 emissions through utilization of renewable energy, the team will develop a renewable energy network to reasonably and effectively introduce renewable energy into the existing energy network. In particular, it studies smart control of power conditioners (PCS), 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.

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



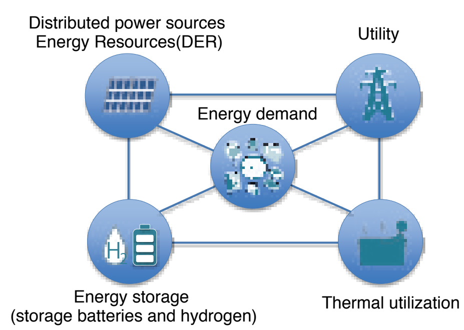
Solving problems regarding the stabilization and countermeasure costs for mass introduction of renewable energy

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 renewal 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 PV modules, PV inverter performance tests, field failure diagnosis of a mega solar, etc.
- Production, storage, and use of hydrogen using renewable energy: a direct electrolysis technology from PV modules (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 energy resources: 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.



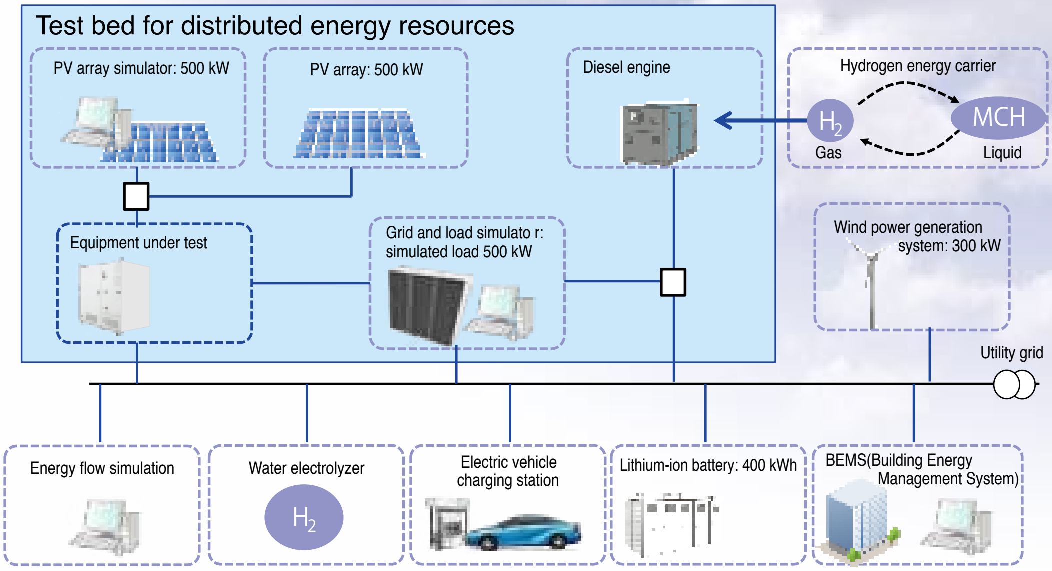
Technological items that the energy network team deal with

Main Research Facilities

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

On this platform, EMS (Energy Management System) shall be developed and demonstrated through PV systems that consists of different technologies from ten companies), large power grid simulator (Smart DER System Research Facilitiy 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 EMS evaluation linked 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



DER-demonstration platform

Activities and Achievements

①System integration technology and energy management

The team conducted a performance analysis of individual elemental technologies, including a solar photovoltaic PV power system comprising more than ten types of PV modules and three types of 22 power conditioning systems (PCS), a proton exchange membrane type 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 with in Fukushima Prefecture on a massive scale through the Fukushima-Prefecture Renewable Energy Next-Generation Technology Development Project (FY2013–FY2014). It allows 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 PV with proton exchange membrane type 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 aims at realizing dissemination of FCV and realization of hydrogen societies by developing related technologies.

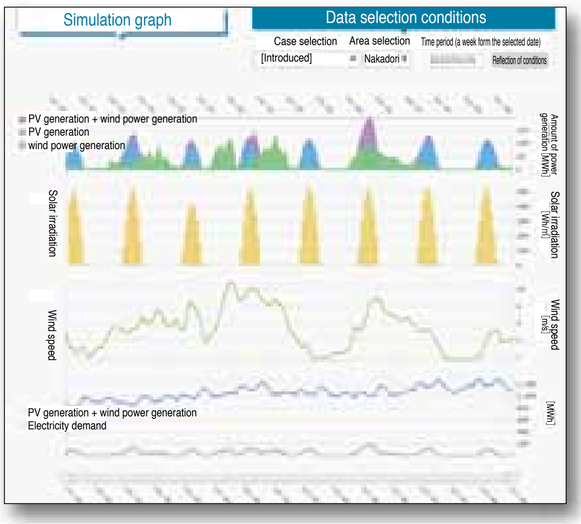


Fig.1: Renewable-energy power-generation observation system
(http://www.solar.fukushima.jp)

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 natual 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/or quite dependent 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

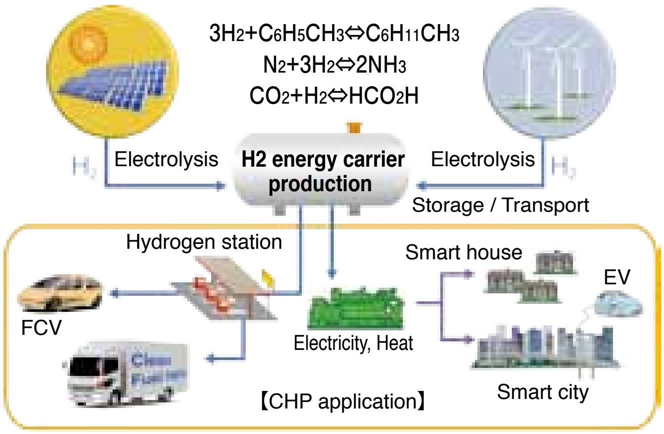
The team has great challenges to solve energy issues by developing technologies of energy storage and utilization for a massive penetration of renewable energy in the future.

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 fiuctuating 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,formic acid). 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.
  ※Formic Acid: Organic compound containing 4wt% hydrogen, which is liquid at room temperature and atomospheric pressure. Formic acid is produced by synthesising carbon dioxide and hydrogen. One L of formic acid stores 600 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.

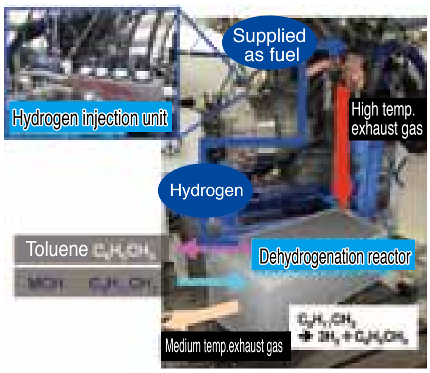


Main Research Facilities

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 Nm^3/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

Activities and Achievements

①Evaluation 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.

②Unified 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. 10 MWh of electricity (Equivalent to 1000 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 FREA to suggest a strategy for electricity storage and utilization.

③Advanced Co-generation Engine by use of H_2 from 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.

④Development 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 burning methane-ammonia gas or 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).

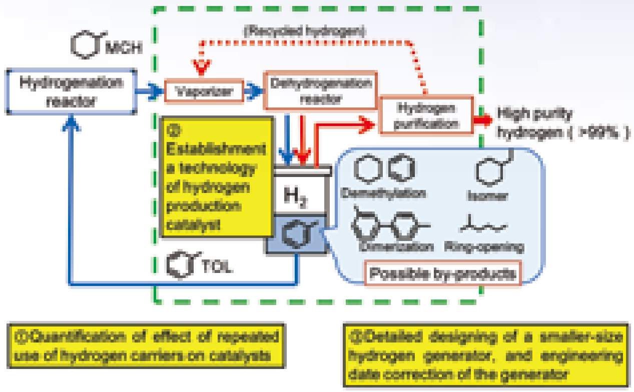


Fig.1: Hydrogenation and dehydrogenation cycle of MCH

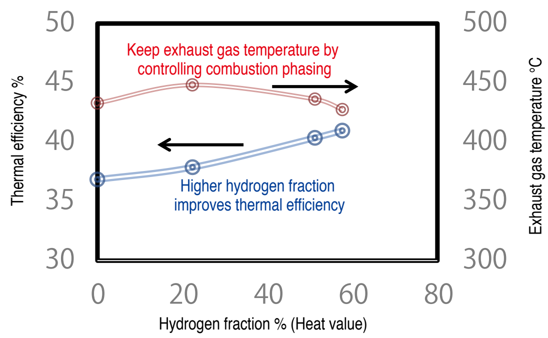


Fig.2: Thermal efficiency and exhaust gas temperature as a function of the hydrogen ratio of the next-generation cogeneration engine

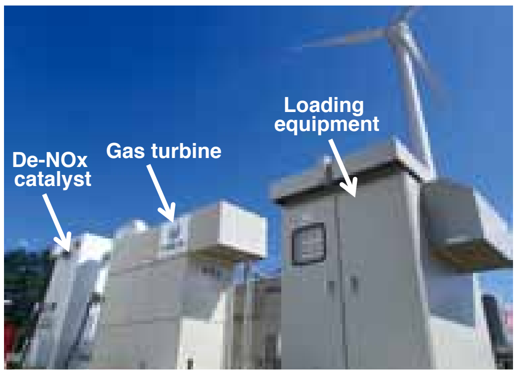


Fig.3: Ammonia Gas Turbine

Wind Power Team

—Advanced Technology for Wind Power Generation—

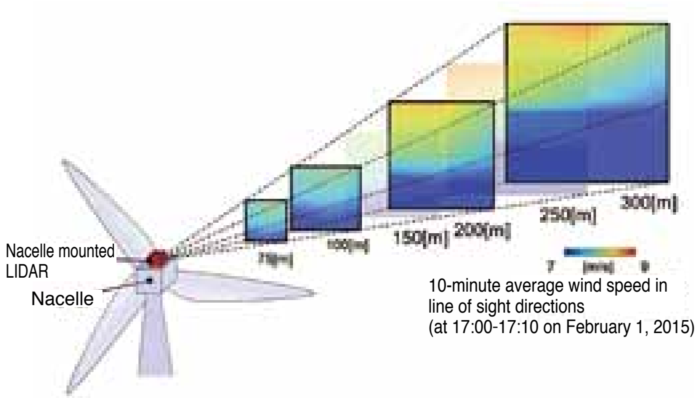
The further reduction of power generation costs is indispensable to accelerate the introduction of wind power generation and to achieve grid parity although the practical application of the wind power generation has progressed. Both the hardware aspect of wind turbines and the software aspect such as assessment technologies for the suitable site selection based on the high-quality wind assessment and the wind forecasting are needed to achieve the further cost reduction.

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 robust promotion of the domestic introduction 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 amount of power output 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 ±5% or less as well as the reduction of measurement and assessment costs by 20%-30% by achieving the advancement 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: Light Detection and Ranging
(a device for the remotely measuring wind speed and wind direction by laser light)

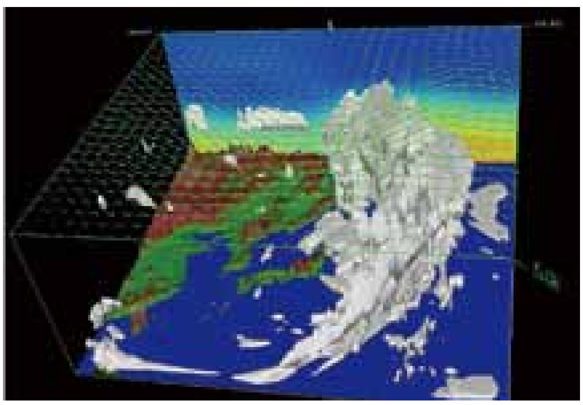
Research Outline

①Elemental technologies for a high-performance wind turbine

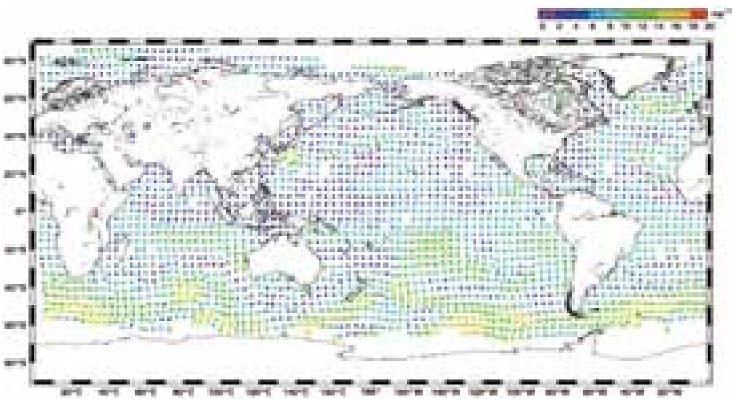
The team will develop and demonstrate a high-performance prototype of nacelle mounted LIDAR as a new promising technology for measuring the wind speed and direction in the upstream side of a wind turbine. This technology can improve the wind turbine's power output by performing the feed-forward control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

②Offshore wind resource assessments using a numerical model and satellite remote sensing

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 made cooperation and contributions through joint studies at the design stage.

Ground based LIDAR
It is a device that remotely measures the wind speeds 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.

Activities and Achievements

①Field 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 ±10° based on the information about the wind direction in front of a wind turbine obtained with the nacelle mounted LIDAR.

②Advanced 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 ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) 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 et al., 2015), which resulted in the significant improvement of the reproducibility of atmospheric stability near the sea surface.

③Advanced 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.

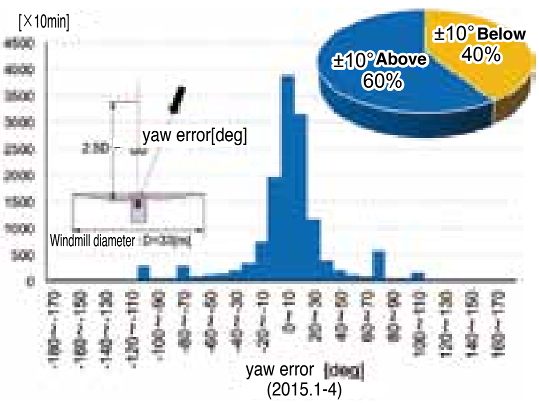


Fig. 1 Histogram of the yaw error (an error in the wind turbine direction against the inflow wind direction)

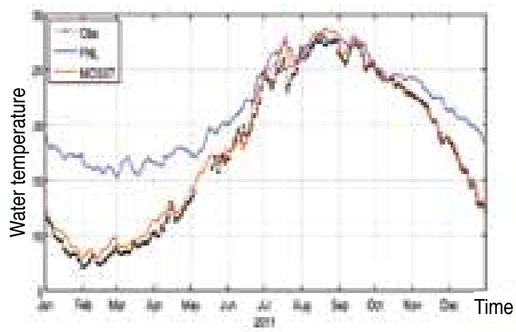


Fig. 2 Comparison between various sea surface temperature datasets and measured data (Osaka Bay)

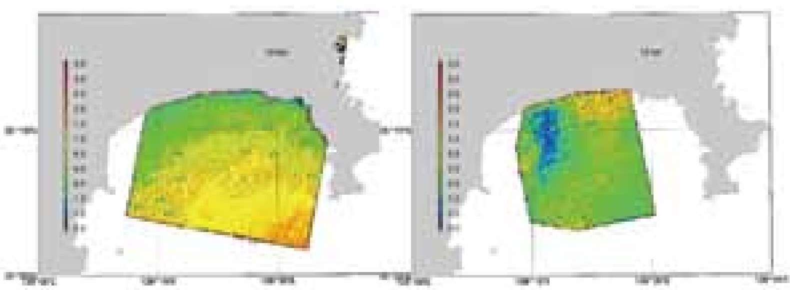


Fig. 3 The difference between a measured value on an ocean observation tower (1 km offshore) and a retrieved SAR wind speed (Hiratsuka)

Photovoltaic Power Team

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

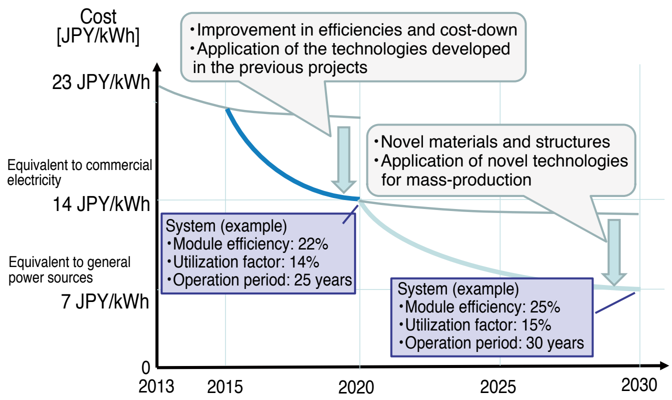
A large number of photovoltaic (PV) systems have been installed under Feed-In Tariff (FIT) since July 2012. In addition to the conventional installation on house rooftops, many large-scale power plants so called “mega solar” have been constructed. Reduction in PV power generation cost is very important 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.

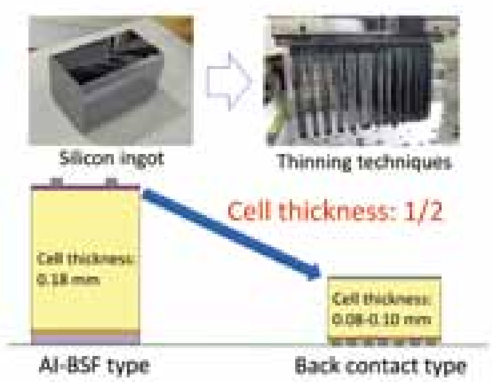


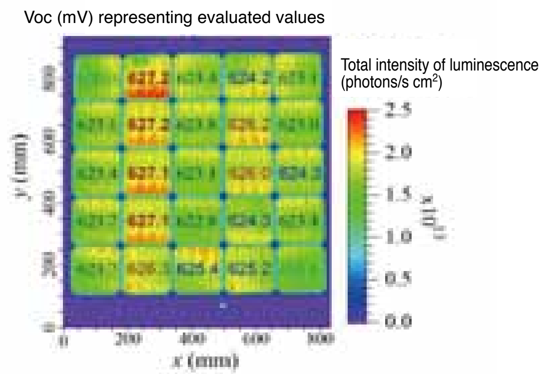
Figure of thinning process of wafer (cell)

●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.



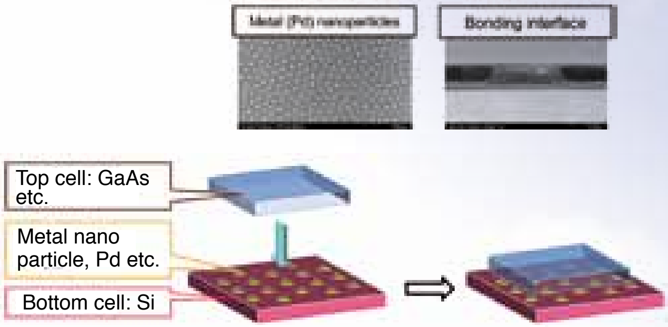
Voltage mapping by the absolute electroluminescence method

●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 demonstrative GaAs/Si three-junction with a conversion efficiency of 24.7% was successfully fabricated.



Smart stack technology

GaAs/Si-based three-junction smart stack cell

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

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.

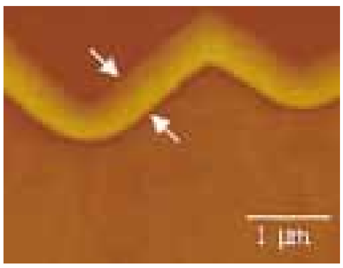
③The smart stack technology was applied to a GaAs/Si-based three-junction cell to achieve a conversion efficiency of as high as 24.7%.

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 19.1%.

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

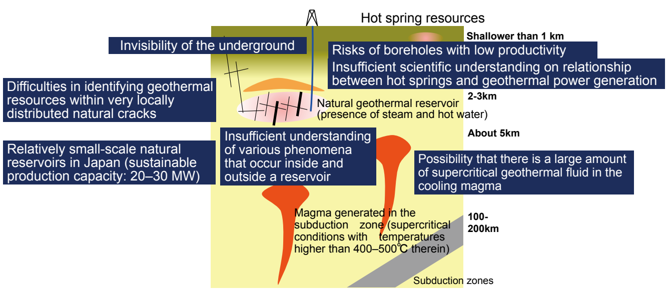
Geothermal Energy Team

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

Japan has many volcanoes and a vast amount of geothermal energy. Geothermal energy contribute to the stable power without effects of weather conditions. Geothermal energy has a potential to cover a base load power.

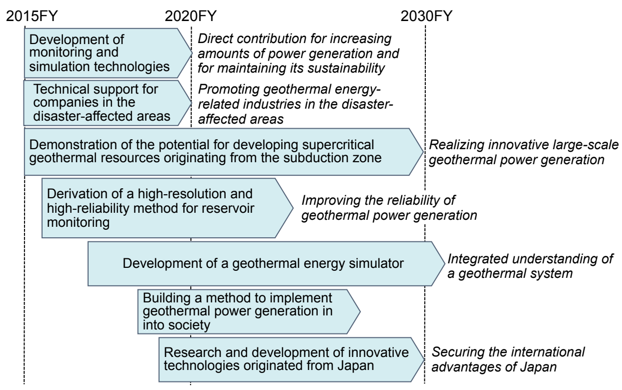
Research Target

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

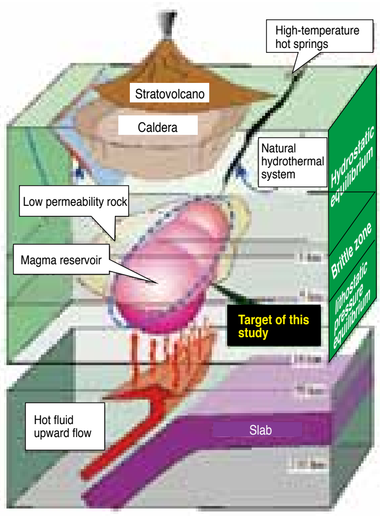
Research Outline

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 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:

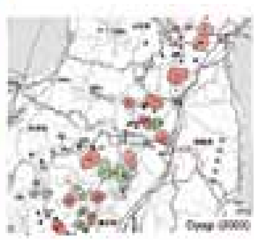
- Understanding and visualizing the phenomena that occur in the reservoir by developing a sensing system for monitoring geothermal energy using Micro Electro Mechanical Systems (MEMS), optical fibers, etc. and by developing advanced analysis technologies such as transient multicomponent signal processing and 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 us to derive a universal development and utilization method.
- Exploring the possibility in developing 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.

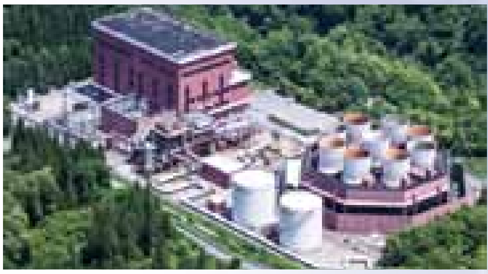


Concept of a supercritical geothermal system

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 caldera (4-5 km). There are more than 50 old calderas in the Tohoku region.

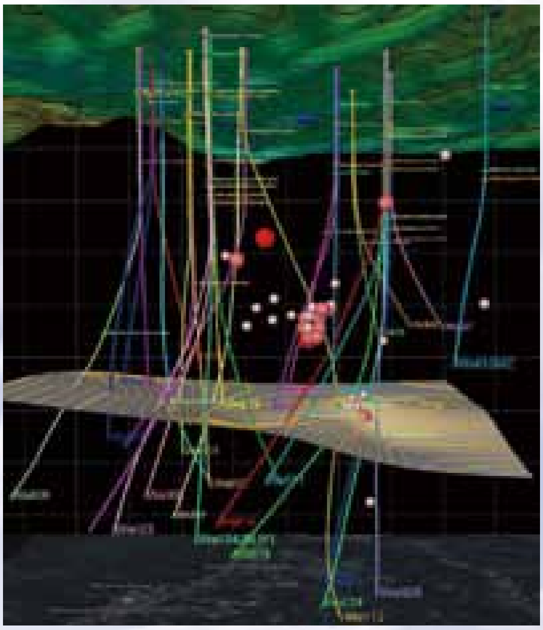


Distribution of old caldera (Oyagi, 2003)



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

Status of installing the three-component seismometers



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

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

Main Research Facilities

Examination device of hot spring system
The device simulates a pipeline of hot spring in the laboratory for the evaluation of hot spring monitoring sensors, the experiment of a hot spring power generator.

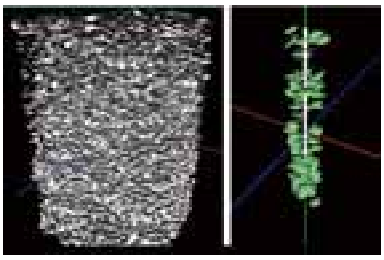
Downhole three-component accelerometer for a geothermal well
It is a downholetool that can detect extremely small earthquake motions occurring inside and outside the geothermal reservoir developed by AIST.

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.

Activities and Achievements

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

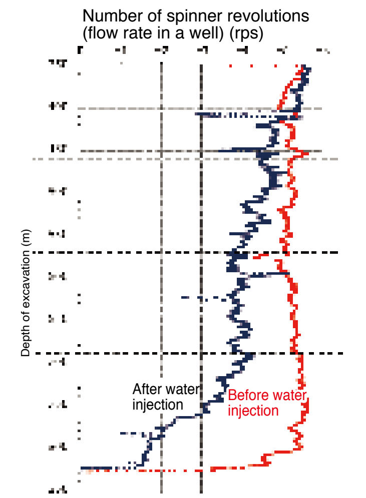
In some case, the capacity of a geothermal reservoir is improved by water injection to the reservoir through a geothermal well. The geothermal energy team collaborated with US and European researchers and developed a simulator for simulating the response of a crack for water injection. As a result of 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

②Development 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. The performance evaluations by laboratory experiments and field demonstration tests run 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 1980s after the world oil crisis in 1970s. Although it is not a new technology, its spread in Japan has been delayed for it was hardly known until around 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.

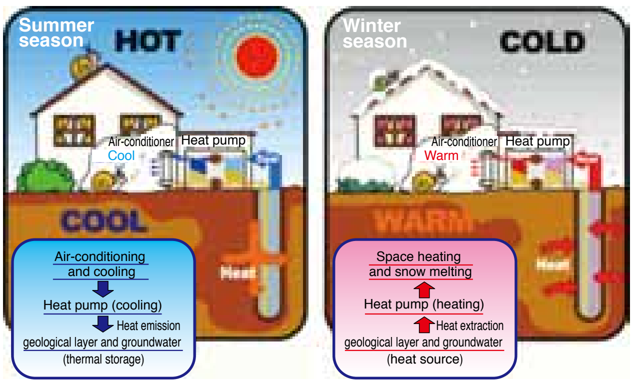
Research Target

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

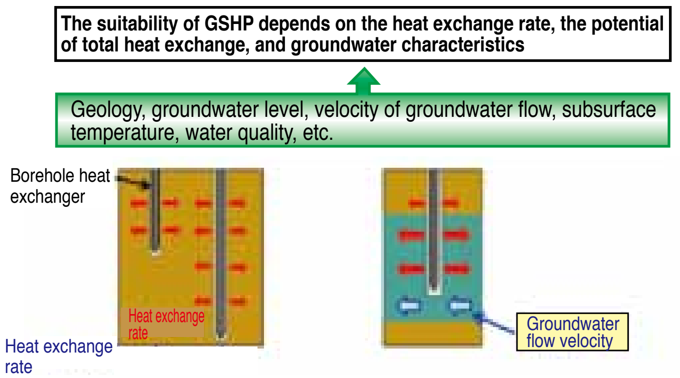
There are two types of GSHP system: a closed-loop system exchanges heat by circulating brine or water in pipes buried in underground while an open-loop system pumps up groundwater to exchange heat at the ground surface. In Japan, since the existence of groundwater and its flow rate largely affects the heat exchange rate in both cases, it is important to investigate the water level and flow-rate of the groundwater. Such a 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 a site:

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

※COP: Coefficient of Performance



Concept of a ground source heat pump system



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.

Research Outline

To use GSHP, it is important to understand the subsurface hydro-geological condition of the site. We, therefore, conduct geological survey by boring, 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 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 hydro-geological settings.

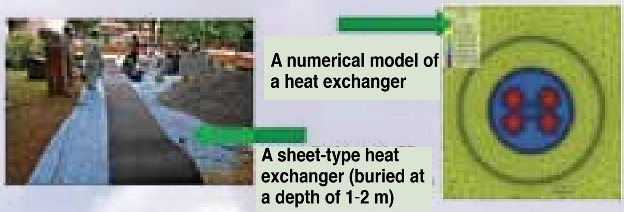
The team is mainly engaged in the following research and development themes:

●Research on GSHP suitability assessment

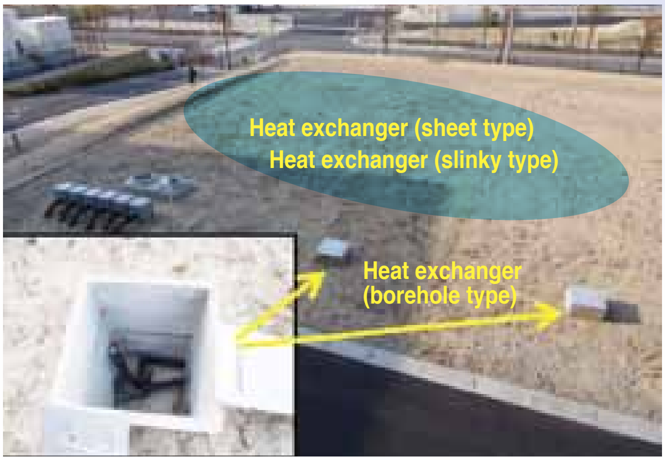
In Japan there are many regions where groundwater is so abundant at a depth of several meters to 100 m, so that utilization of GSHP system should be more efficient if flowing property of groundwater is considered. In order to promote appropriate GSHP system utilization, the team conduct research and 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

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).

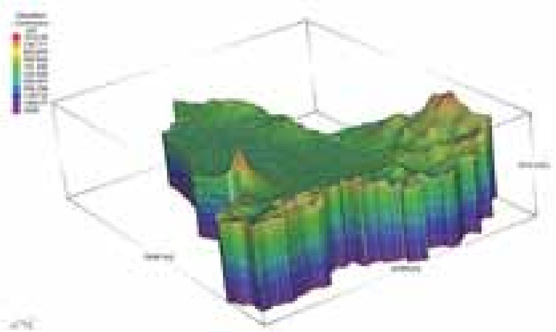


Fig. 1: Three-dimensional groundwater-flow and heat-transport model of the Tsugaru Plain

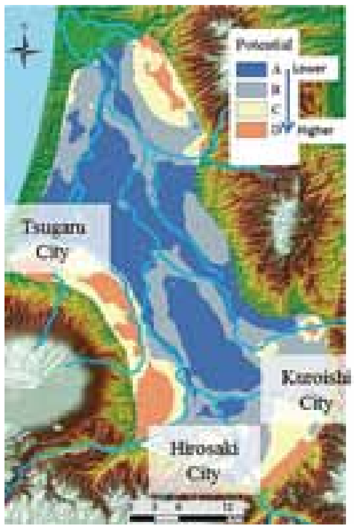


Fig. 2: A new suitability map

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

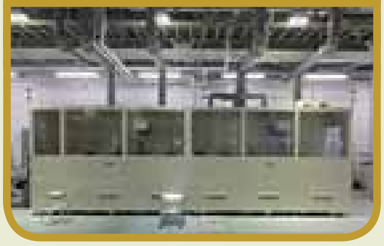
An integrated manufacturing line of thin crystalline-silicon solar cells was provided in a separate laboratory of FREA to develop a mass-production technology for solar-cell modules with high efficiency, low cost, and high reliability. In this line, cells with conversion efficiency equal to or greater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

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

①Silicon Ingot Slicing (Wafering)

Multi-Wire Saw

②Surface Texture Formation



Surface Texture Formation Machines

③PN Junction Formation

Thermal Diffusion Apparatus

Ion Implantation Machine

④Antireflection Film Deposition

PE-CVD Machine

⑤Electrode Printing and Firing

Electrode Printing and Firing Machine

⑥Photovoitaic Module Fabrication and Reliability Test

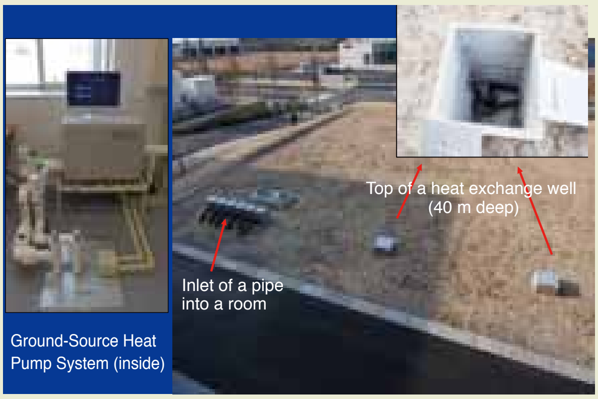
Vacuum Laminator

Reliability Test Machines

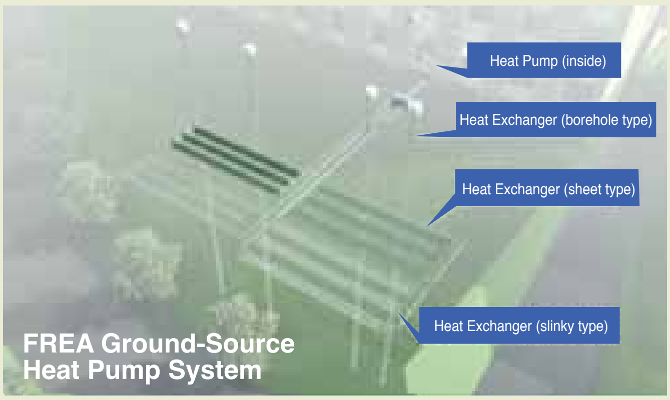
Ground-Source Heat Pump System Demonstration Area

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

①Energy Control Building

The team is conducting studies on a renewable energy network through the integration of large-scale PV and wind power systems with power storage with 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 piece for each type)
- Solar simulator for a 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

②Hydrogen 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 Nm^3/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

③Pure Hydrogen Experiment Building

The team is conducting researches 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)

④Photovoltaic 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 m^2

⑤Wind Power Generation System

The team is conducting the verification of the Japan-class 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 power 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 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

⑥Ammonia 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 burning 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 opened in April 2016, such as large PCS essential for the introduction of renewable energy.

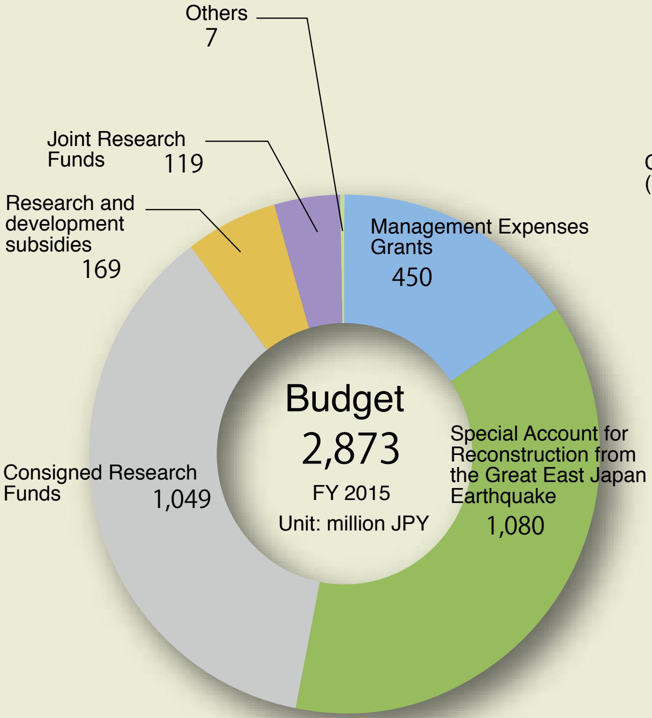
It becomes a user facility for the performance test of DER and the performance verification of an EMS that integrates DER on an actual scale.

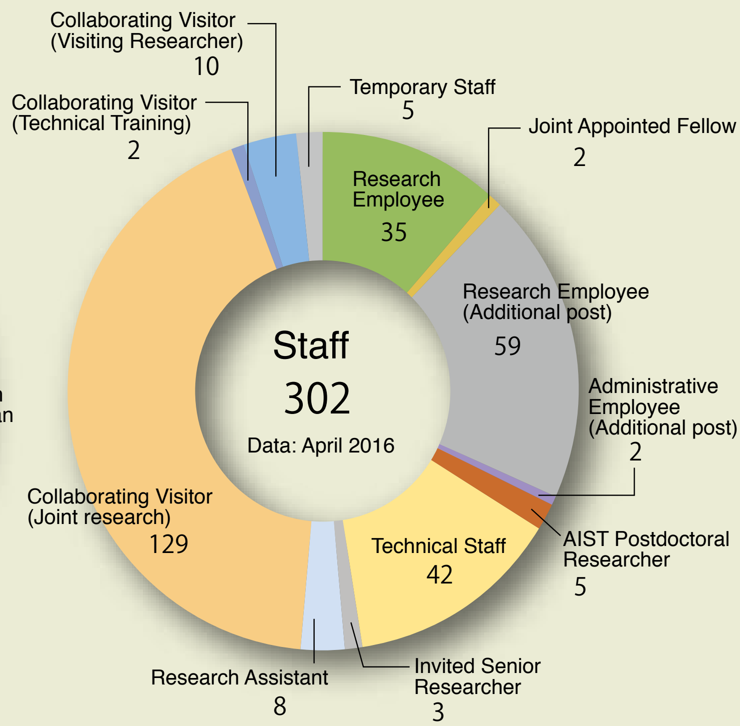
By cooperating with international research institutes, the team aims at the international standardization and the international certification of the products.
The following four kinds oftest laboratories will be installed at the facilities:

Smart System Research Facility (April 2016: expected opening)

1. Grid Connection Test Lab.	The largest grid connection test laboratory in Japan accommodating a 20-foot-long container to conduct grid connection tests up to 3MW, and simulation power distribution line.
2. Safety and Reliability Test Lab.	A large-size environmental test laboratory to conduct environmental tests such as a temperature and humidity cycle test, assuming use in desert areas, high-temperature and humidity areas, and very cold areas. It addresses a temperature range from -40°C to +80°C and a humidity range from 30%RH to 90%RH.
3. Electromagnetic Environment Compatibility (EMC) Test Lab.	The largest anechoic chamber in Japan, approx. 5 times larger than a tennis court, is used in electro-magnetic compatibility (EMC) tests of power electronics devices and ICT devices, which are indispensable for smart grid systems.
4. System Performance Test Lab.	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).

Budget and Staff





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 82 cases (38 companies) so far, three of which (“solar cell string monitoring system”, ”bypass diode checker” and “Crosslinking coagent for encapsulants in PV modules” in the right figure) succeeded in practical application as a new project, whereas some of which are starting to provide specific outcomes such as the state close to their practical application

Joint research and collaboration (results in FY 2015)

●”Program for Promoting Technologies Invented by Industry in Disaster Areas in Tohoku”	25
●Joint research with local universities:	16
●Joint research with companies:	43
●Other joint research:	11
Total number	95

Main upbringing human resources (results in FY 2015)

●AIST Postdoctoral Researcher	5
●Research Assistant	15
●Technical Staff	23
●Technical Training	21
Total number	64

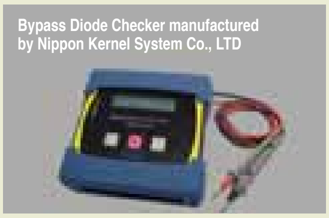
●Renewable energy field through the joint research with the institute

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.

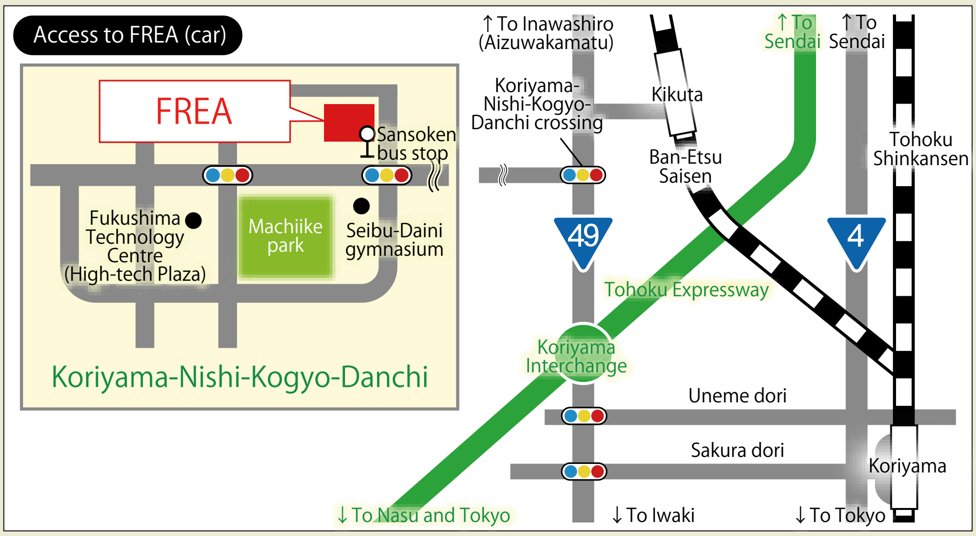

High-performance crosslinking coagent for EVA encapsulants in PV modules by Nippon Kasei Chemical Co., Ltd

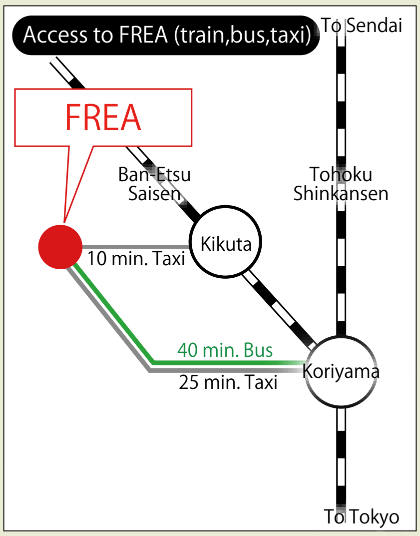
Crosslinking coagent for encapsulants in PV modules

The crosslinking coagent has been productized with AIST’s technical support to enhance the reliability of sealing material (EVA: ethylene-vinyl acetate) used in PV modules.

By using this coagent, it is possible to enhance the reliability of PV modules without altering the production process or raising the cost.

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 oversea research organizations. Please visit the following website for details.

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

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