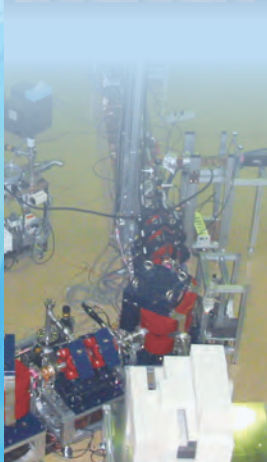
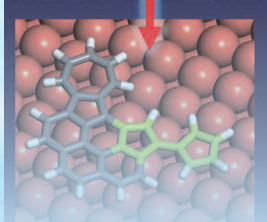
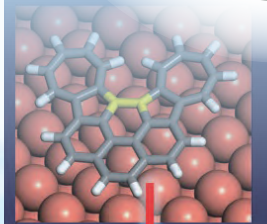


2022



# Institute of Advanced Energy

Kyoto University

<http://www.iae.kyoto-u.ac.jp/en>

# Foreword



Director  
Takashi Morii

The Institute of Advanced Energy (IAE) was established in May 1996 to explore the energy systems for next generation by going back to the basic principles of nature, and to create new energy theories and technologies for the next generation. Currently, faculty members belonging to the Faculty Consort of Advanced Energy in the Natural Science Platform are engaged in 14 research sections in three divisions, each of which investigates one of the following three basic processes of energy: generation, conversion, and utilization. The institute has set up the Laboratory for Complex Energy Processes with five research sections, which supports and stimulates collaborative research to address issues related to complex energy processes.

The two core research areas of the institute are “Plasma and Quantum Energy Science” and “Soft Energy Science.” The former aims to realize nuclear fusion to generate solar energy on earth. The latter aims to achieve highly efficient energy utilization and conversion based on the principles of materials science and energy use by living organisms, which have built the biosphere on earth with solar energy. In addition to actively promoting the internationalization of research and the return of research results to society through industry-academia-government collaboration, we educate students of Liberal Arts and Science Courses and the Graduate School of Energy Science as the Cooperating Chair, foster young researchers in a front-line research environment.

The Joint Usage/Research Center for Zero-Emission Energy, a project accredited by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) in FY2011 will enter its third phase of activities in FY2022, and will further contribute to the zero-emission energy-related research community. As the research hub of Zero-Emission Energy, we collaborate with domestic and overseas researchers over a broad spectrum of academic fields, as well as promote the share-use of cutting-edge research equipment to strengthen the foundation of academic research and to accelerate novel scientific research. In addition, we are also participating in the “Kyoto University Research Coordination Alliance,” which promotes collaboration among the university’s research institutes and centers, and the “Uji Campus Base of Equipment Support,” which makes effective use of advanced research facilities, and are actively promoting collaborative projects with other departments within the university. With the Graduate School of Energy Science, we are expanding our educational and research activities internationally at the “International Advanced Energy Science Research and Education Center.”

In Japan, too, the goal of “virtually eliminating greenhouse gas emission by 2050” has been set, and carbon neutrality is now a goal for societies worldwide. In order to achieve virtually zero greenhouse gas emission, it is necessary not only to effectively introduce existing technologies in the processes of energy generation, conversion, and utilization, but also to create new theories and technologies from various scientific perspectives. IAE has been committed to pursue a wide range of research aimed at Zero-Emission Energy, which will play an increasingly important role in achieving carbon neutrality and providing a variety of new energy technology options that can respond to infectious diseases, natural disasters, and other problems. A new research center for carbon negative energy research, to be established in FY2022, will work with the Graduate Schools of Energy Science and Engineering, to create new concepts, academic foundations, and science and technology for the effective use of carbon dioxide to realize a carbon neutral society in 2050.

Under the liberal academic culture of Kyoto University and significance in promoting original and creative research, all the members of the IAE, including Vice Director Hideaki Ohgaki and Director Masato Katahira of the Laboratory for Complex Energy Processes, will strive for research activities, education, and international and social contributions. We look forward to your continued support.

A handwritten signature in black ink that reads "T. Morii". The signature is written in a cursive, flowing style.



## CONTENTS

Foreword .....	1
Mission and Goal .....	3
Organization Chart .....	4
History .....	5
Overview of Divisions and Faculty Members .....	7
▶ Advanced Energy Generation Division	
▶ Advanced Energy Conversion Division	
▶ Advanced Energy Utilization Division	
▶ Laboratory for Complex Energy Processes	
Adjunct Faculty Members .....	22
Overview of Laboratory for Complex Energy Processes .....	23
Organization of Research Projects in the Laboratory .....	25
Major Projects .....	26
Research Facilities .....	31
Education and Social Activities .....	35
International Activities .....	37
Data .....	39
Admissions .....	40
Access to Kyoto University .....	41

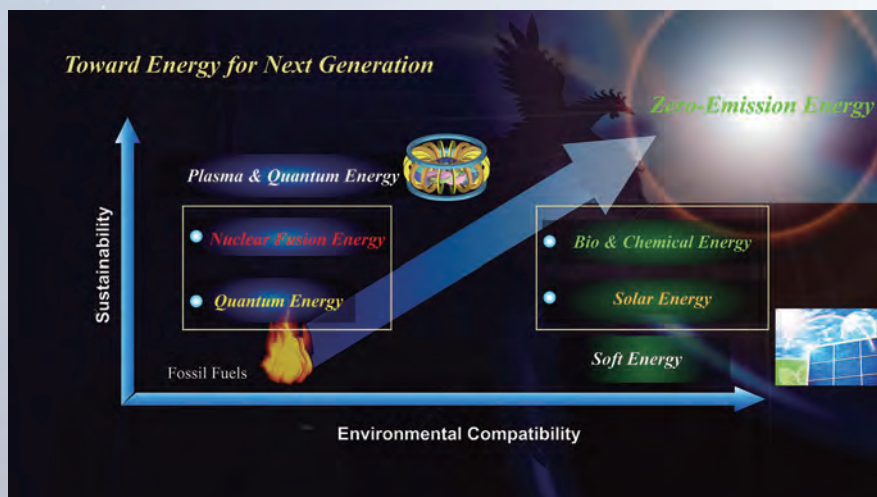
# Mission and Goal

The Institute of Advanced Energy (IAE) was established to promote researches to sophisticate the generation, conversion, and utilization of energy. Our goals are (a) to conduct pioneering research on advanced energy science and technology, (b) to propose solutions to energy and environmental issues associated with rapid global population expansion, and (c) to contribute to the sustainable progress of humankind.

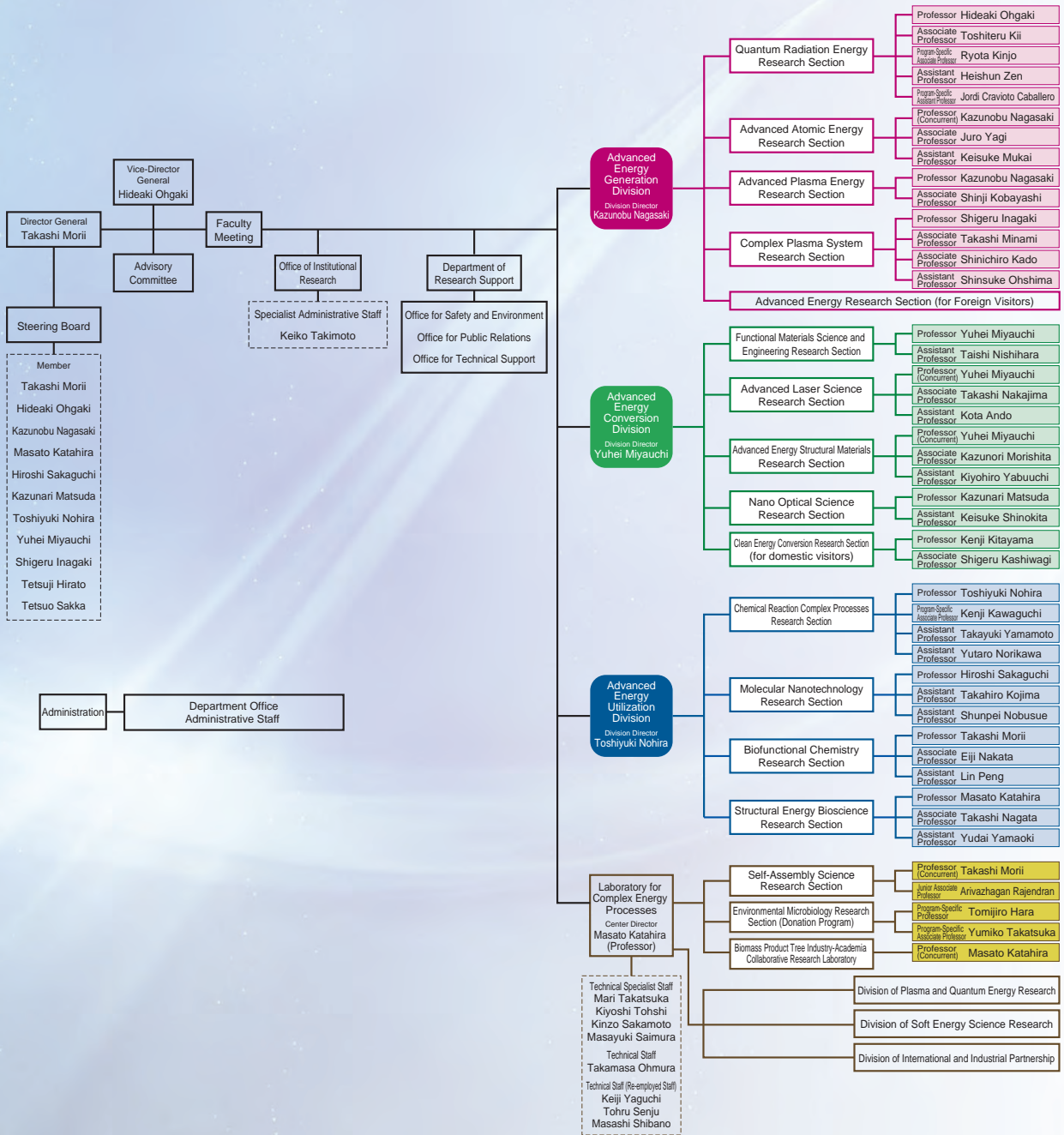
We perform a comprehensive approach towards development of next-generation energy systems, which have the potential to replace existing energy systems, with two viewpoints, Quality (harmonization with the environment) and Quantity (social infrastructure). In order to secure sustainable energy resources or systems, our research activities emphasize improving the performance of energy systems, developing new energy resources, and realizing systems for effective use of energy resources, which can be termed as the Zero-Emission Energy System. Moreover, through these endeavors, we aim to foster scientists and engineers who possess advanced knowledge and skills in the energy science and technology.

To meet our objectives, we strive to further explore the research field of Advanced Energy or Zero-Emission Energy by innovating an energy system with high social receptivity and a system capable of incorporating various sources of energy. The human and research resources at IAE are consisted of diverse academic backgrounds. This characteristic provides a unique opportunity to promote interdisciplinary researches coordinated by seemingly different research fields. By taking advantage of these activities, IAE serves as a hub for advanced energy research in Japan and around the world.

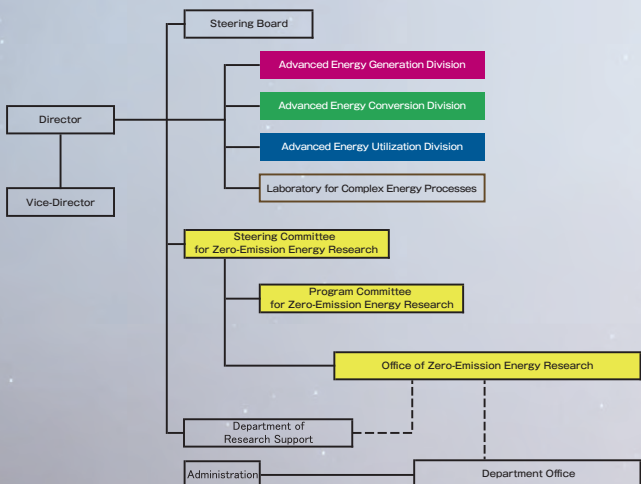
These activities will further develop the advanced energy research to contribute to the next generation and contribute to the sustainable growth of society.



# Organization Chart



## Organization for Zero-Emission Energy Research Project



# History



Engineering Research Institute



10th Anniversary of Kyoto University Engineering Research Institute



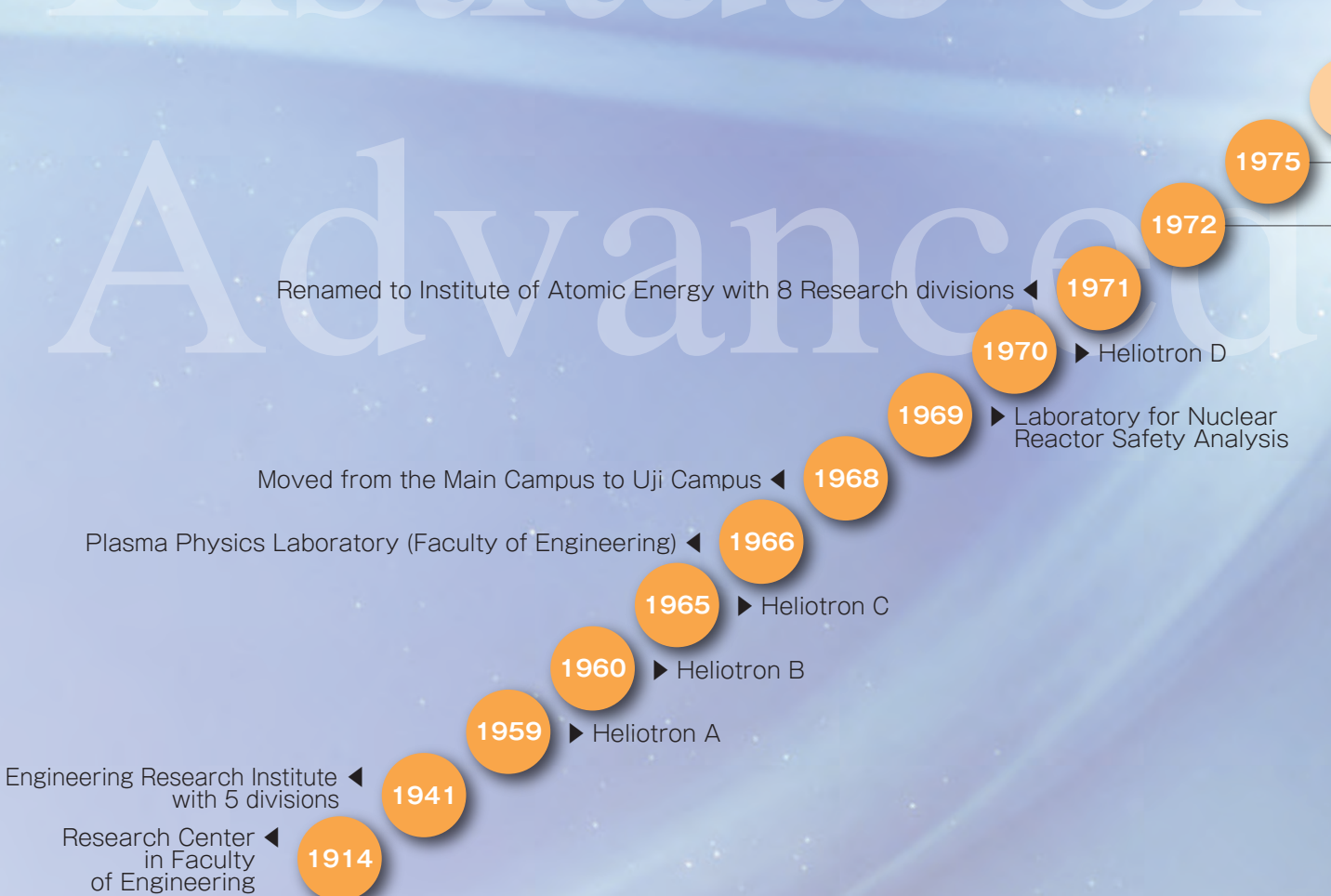
Institute of Atomic Energy

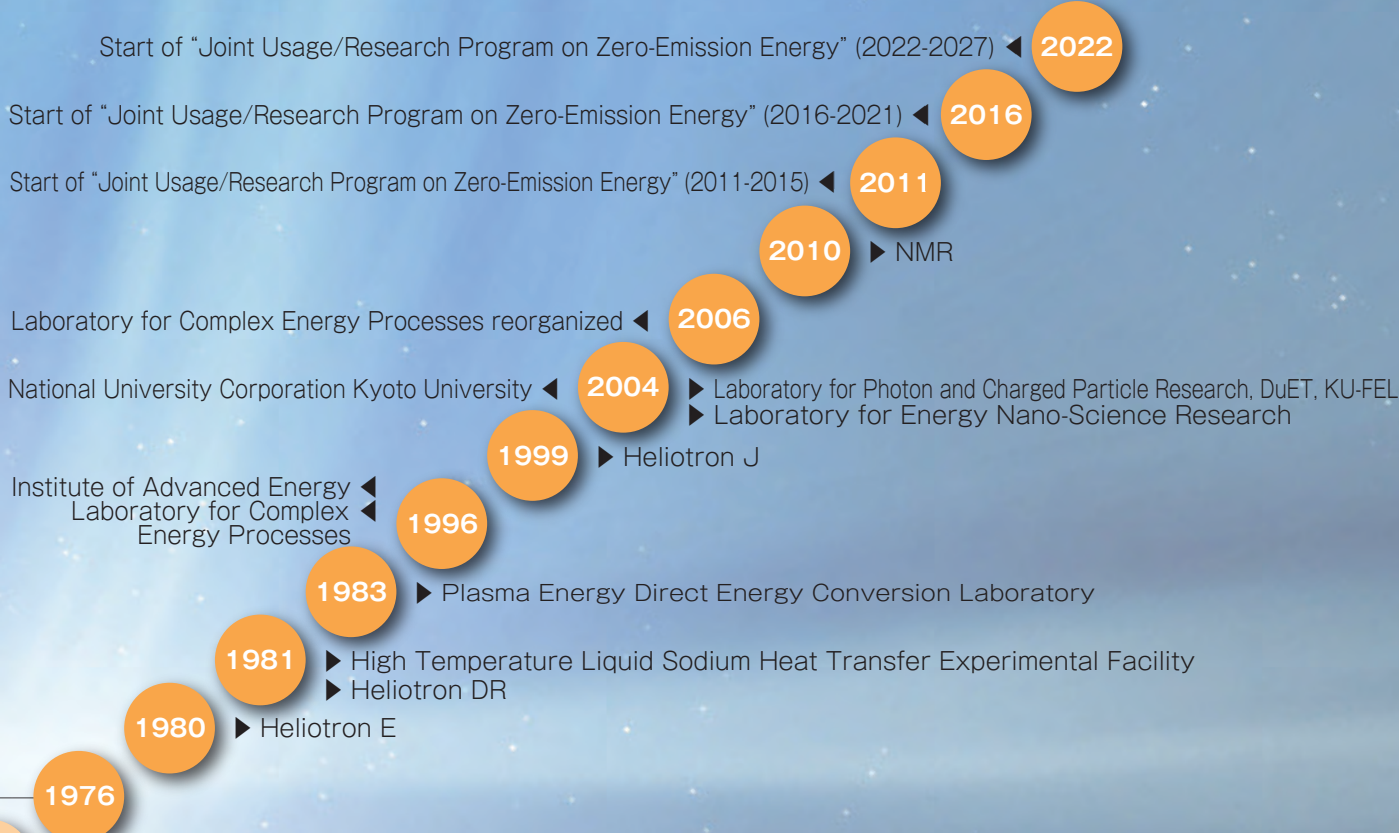


Institute of Advanced Energy Inaugurated

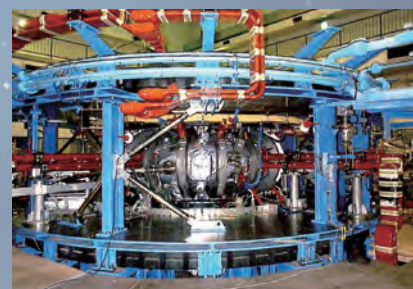
# Institute of Advanced Energy

Plasma Physics Laboratory ←





# Energy



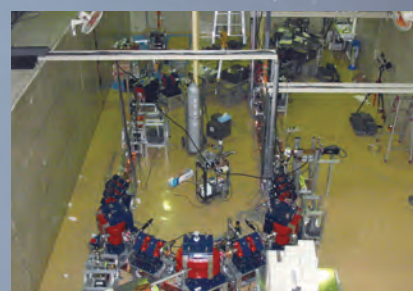
Heliotron J



DuET



NMR



KU-FEL

## Division Introduction

### Advanced Energy Generation Division

We promote the development of socio-friendly and fundamental "zero-emission energy system" that should be an inevitable issue sustainable future of humankind, and innovative energy sources with particular function including their application technology.

### Advanced Energy Conversion Division

Aiming at the efficient conversion of energy functions and the generation of new energy functions, this division studies fundamental energy-material interaction and its applications, efficient energy-conversion processes, and the development of functional energy materials.

### Advanced Energy Utilization Division

The aim of division is the establishment of 'Emergent Materials Science' having a similar concept seen in energy-related processes in nature, efficiently converting 'soft energy' into 'electricity' and 'valuable chemicals' without huge consumption. The research projects ongoing cover the researches of energy-related materials sciences, chemistry and biosciences for the development of new technologies for renewable energy conversion and utilization.

### Laboratory for Complex Energy Processes

This Laboratory is a core research center for strategic and multidisciplinary collaboration studies in IAE, offering cooperative project activities in the field of the advanced energy. The Center has three divisions : (1) "Division of Plasma and Quantum Energy Research", for fusion and related advanced energy studies, (2) "Division of Soft Energy Science Research", that promotes innovative functional materials based on nanotechnology and biotechnology, and (3) "Division of International and Industrial Partnership" that promotes and enhances activities and relationship with foreign and domestic research partners including industry and private sector. Corresponding to the two research areas, "Self-Assembly Science", "High-Temperature Plasma Equipment Engineering", "Broad Band Energy Science", the Donation Program "Environmental Microbiology", and "Biomass Product Tree Industry-Academia Collaborative Research Laboratory" research sections belong to the Laboratory.

## Interactions among Divisions

The Institute of Advanced Energy has three divisions including "Advanced Energy Generation Division", "Advanced Energy Conversion Division", and "Advanced Energy Utilization Division". Each division consists of researchers pursuing a variety of scientific research programs as described in the next section. These ongoing research programs aim to establish state-of-art technology for the energy systems in the next generation, especially our current target, the "Zero-Emission Energy" system, which is indispensable for the sustainable development of humankind.

In addition to these research activities ongoing in the Divisions, the interdisciplinary collaborative research programs surely accelerate the development of "Zero-Emission Energy" system. Towards this goal, the Laboratory for Complex Energy Processes is established to support interdisciplinary collaborative research projects among the researchers in three divisions since the establishment of the laboratory. Such collaborations through the projects now focus on two research categories of "Plasma & Quantum Energy" and "Soft Energy". This multilayered structure of our research activities has enhanced the comprehensive capabilities of the institute, thereby creating a distinctive characteristic of our institute.



## Quantum Radiation Energy Research Section

Research on Generation and Application of New Quantum Radiations, i.e. Compact MIR Free Electron Laser, Table-Top THz coherent radiation, and Laser-Compton Gamma-ray. International collaboration research on renewable implementation in ASEAN.



Professor  
Hideaki Ohgaki



Associate Professor  
Toshiteru Kii



Program-Specific  
Associate Professor  
Ryota Kinjo



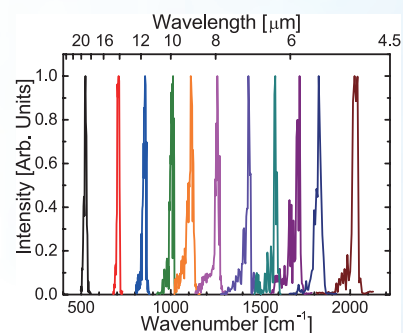
Assistant Professor  
Heishun Zen



Program-Specific  
Assistant Professor  
Jordi Cravioto Caballero

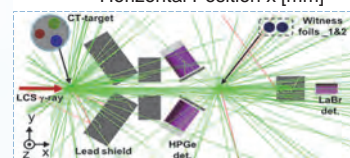
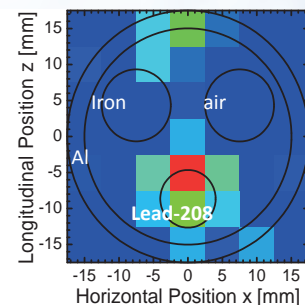
### Generation and Application of New Quantum Radiation

Generation and application of new quantum radiations from relativistic electron beams have been studied. Free electron laser, which is generated by a high brightness electron beam from an accelerator, is a tunable laser with high power. We have developed a thermionic cathode RF gun with our original RF control system to generate mid-infrared FEL with a compact accelerator system. In 2008 we succeeded in FEL power saturation at 13.6  $\mu\text{m}$  in wavelength and now the FEL can provide the intense laser light in the wavelength region from 3.4 to 26  $\mu\text{m}$ . As application researchers, we promote the mode-selective phonon excitation experiment to study wide-gap semiconductors in cooperation with in-house users as well as outside users. Generation and application of Laser-Compton Gamma-ray beam have been studied for the nuclear safeguard and security technology. A short period undulator consisting of bulk high Tc superconducting magnet and table-top THz coherent radiation have been studied. We promote international collaboration research on renewable energy implementation in ASEAN as well.

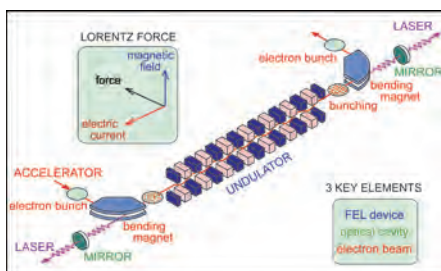


#### Wavelength Tunability of KU-FEL

This graph shows the wavelength tunability of KU-FEL. We can freely change the FEL wavelength from 3.4 to 26  $\mu\text{m}$  by changing the electron beam energy from 36 to 20 MeV. The spectral width of the FEL is around 1–3 percent in FWHM.



Isotope CT by using Laser-Compton Gamma-ray beam  
Isotope mapping by using Laser-Compton Gamma-ray beam generated in collision of electron beam and laser has been developed to apply nuclear safeguard.



#### Principle of FEL

Generation of Free Electron Laser (FEL) is based on the micro-bunching phenomenon driven by a high brightness electron beam which interacts with electro-magnetic field.

## Advanced Atomic Energy Research Section

We design and develop the zero-emission energy system powered by fusion, from its generation to utilization, and analyze it from environment, socioeconomics, and sustainability aspects.



Associate Professor  
Juro Yagi



Assistant Professor  
Keisuke Mukai

Professor (Concurrent)  
Kazunobu Nagasaki

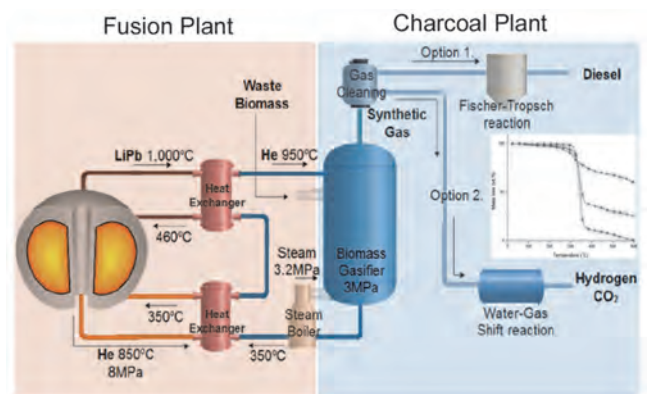
### Design, Development and Assessment of Fusion Energy Systems

Zero-emission energy system that has little constraints of resource and environment is expected to provide ultimate solution for sustainable development of human in the global scale.

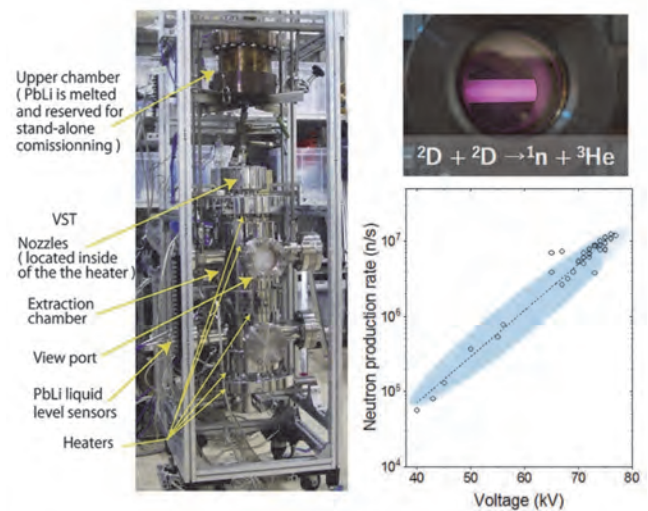
We study the fusion system design and development, as well as the integrated evaluation from social and environmental aspects. Development of new fusion device to generate neutron beam, conversion of fusion energy, and its application for the production of clean fuels are performed. Fusion is investigated from its generation to the application and adaptation to the future society. We are one of the leading research team of fusion technology, and regarded as a key station of international collaboration. Study of "Sustainability" on energy and environment is also our major topic.

### Fusion blanket research

Fusion reactor requires blanket that utilizes neutron to produce fuels. Experimental system for fusion neutron behavior in the simulated assembly with an integrated material system is established as the 1st attempt in the world. Vacuum sieve tray (VST) concept developed by our group is tested to demonstrate the efficient recovery of heat and fuel tritium from liquid lithium lead circulating fusion blankets. Tritium pumping system to reduce tritium inventory in a fusion reactor and impurity reduction method in liquid metal to improve material compatibility are also investigated.



Concept of Fusion-Biomass Hybrid system



Fusion Blanket experiment with fusion neutron source (right), vacuum sieve tray experimental setup (left)

# Advanced Plasma Energy Research Section

High-power microwave system and high-power neutral beam injection for plasma heating and current drive, and plasma diagnostics using microwaves and beam emission spectroscopy are being developed by controlling charged particles and electromagnetic field.



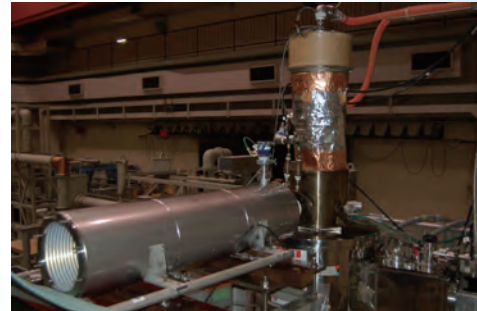
Professor  
Kazunobu Nagasaki



Associate Professor  
Shinji Kobayashi

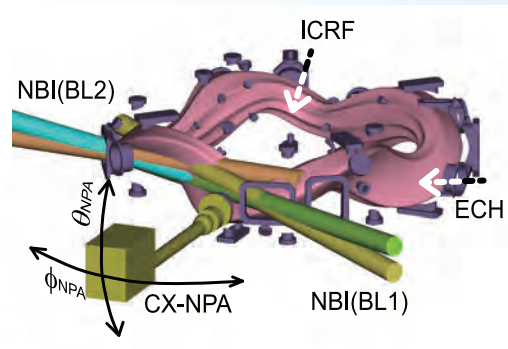
## Development of Advanced Energy by electromagnetic waves and particle beams

Advanced and innovative control methods for the collective behavior of charged particles are being developed in this research section to bring about enormous contributions to the human beings. Emphasized are particularly studies of nonlinear interactions between charged particles and electromagnetic fields. Production, heating, current drive and MHD suppression of fusion plasmas by electron cyclotron resonance are studied by using high-power microwave sources such as magnetrons and gyrotrons and neutral beam injection system. Application of microwaves is also targeted for development of heating and current drive systems. Neutral beam injection system based on high power hydrogen ion sources is used for an attractive scheme for sustainment of high-density plasmas and an effective active actuator of momentum and plasma current, which enables us to control the plasma transport to a preferable plasma confinement condition. In order to realize optimization of magnetic configuration in helical devices, we originally designed and constructed an advanced helical device, Heliotron J in Kyoto University. In the Heliotron J device, we have been also developing plasma diagnostics such as radiometers, reflectometers and active beam spectroscopic systems (charge-exchange recombination spectroscopy and beam emission spectroscopy) to understand the heat, momentum and particle transport. Particle and heat transport in magnetically confined plasmas are studied by computational simulation using transport analysis codes based on heat absorption profile calculations.



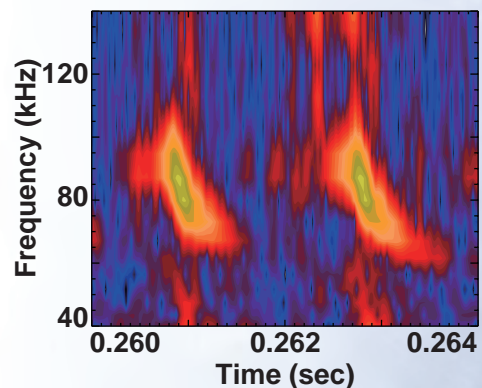
High-power microwave source "Gyrotron"

A gyrotron produces a Gaussian-shaped microwave beam of 70 GHz 500 kW power, which is used for production, heating and current drive of fusion plasmas.



Neutral beam injection system and active beam spectroscopy for Heliotron J

Two beam lines of neutral beam injection system has a maximum applied voltage of 30 keV and maximum injection power of 0.7 MW, respectively. Active beam spectroscopy, charge exchange and beam emission spectroscopies, are being developed to obtain spatiotemporal structure of density, temperature and flow velocity and their fluctuations.



Performance improvement of magnetically confined plasmas by control and suppression of instabilities

Our aim is to have good plasma confinement by means of the control and suppression of several kinds of unfavorable instabilities in high-temperature plasmas, based on experimental and numerical studies. In particular, we are interested in the resonant wave-particle interaction, which leads to risky degradation in a fusion plasma and are commonly observed in nature.

## Complex Plasma Systems Research Section

Various collective phenomena appear in complex plasmas where many structures coexist. Fusion plasma is a typical complex plasma in which collective effects induce new structures and thus the plasma is constantly changing. We aim to understand the laws of this plasma wandering in order to generate fusion energy.



Professor  
Shigeru Inagaki



Associate Professor  
Takashi Minami



Associate Professor  
Shinichiro Kado



Assistant Professor  
Shinsuke Ohshima

Complex collective phenomena appear in plasmas in which many elements and structures coexist. Such a plasma is called a complex plasma. A plasma is a collection of charged particles such as electrons and ions. When the plasma has large energy, collective motions of the plasma, such as waves, undulations, flows, and vortices, are created. Accompanying this plasma motion, heat and charged particles become homogeneous or localized. The resultant inhomogeneity of heat and particles creates new plasma motion, and then the plasma is constantly changing. This "law of plasma wandering" leads to plasma motion on a variety of spatiotemporal scales that cannot be predicted from the motion of individual charged particles.

The "Fusion plasma" is a complex plasma, and it exhibits a great variety of dynamics. In order to realize fusion, we need to understand this complex plasma system. For this purpose, we are trying to clarify the "law of Panta Rhei" of plasmas. Observation is the key to understanding the law. To "observe" it is necessary to create and measure a complex plasma system. In this research field, in order to realize plasma fusion high energy plasma is generated in the plasma experimental device "Heliotron J", and is measured using light and electromagnetic waves, and the data is analyzed. We are working with theory and simulation to explore the "law of Panta Rhei" for thermal fusion.

### Probing What Is Real in Plasma Using Optical Emission

Optical emission from plasmas includes plenty of information such as density, temperature, ionic species and their fluctuations. "Know the enemy (plasma) and know yourself (measurement methods and data), then you can fight the hundred battles without fear" —the real plasma properties that have never been known to anyone will be in our hands.



Plasma emits various line spectra as can be seen through a simple grating film. One can draw huge amount of information from the high-grade spectrographs.

### Temperature and density diagnostic for super-high temperature plasma using the latest laser and optical technologies

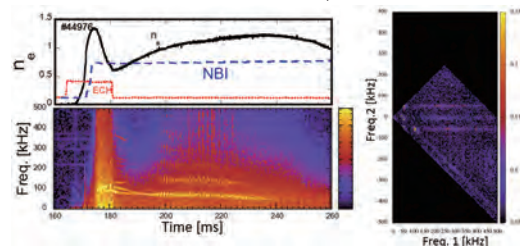
Plasma exists over wide scale range from super-low to super-high temperature and density. If you can know the exact density and temperature, you can know the real plasma properties. We are developing the Nd:YAG laser Thomson scattering diagnostic system based on the latest laser and optical technologies. We will explore the world of over-100-million-degree temperature plasmas into which any diagnostic instruments cannot be inserted.



Nd:YAG laser Thomson scattering system installed in Heliotron J

### Characterization of Plasma Turbulence Based on Spectral Analysis

Confined plasma is, in reality, far from calm. There are many types of turbulent fluctuations growing from the non-uniform plasma parameters. They enhance the transport and degrade the plasma confinement property. For the characterization of the turbulence, we applied various kind of spatiotemporal spectral analysis methods and trying to figure out the correlation between the turbulence and the plasma confinement.



Measurement and signal processing for the turbulent plasma fluctuations. Various spectral analysis techniques are useful for determining the eddy size, frequency and non-linear coupling of the turbulences.

## Functional Materials Science and Engineering Research Section

Our research focuses on the physical properties of nanoscale/quantum materials and their applications in energy conversion/utilization technologies. In particular, materials science and engineering for highly efficient use of solar light and thermal energy are the subjects of interest.



Professor  
Yuhei Miyauchi



Assistant Professor  
Taishi Nishihara

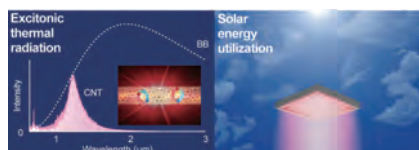
### Energy science based on the functional properties of nanoscale/quantum materials

Our research focuses on the physical properties, functions, and energy applications of materials that exhibit significant quantum mechanical effects, such as carbon nanotubes (CNT) and recently discovered topological materials. The aim is to create new technologies for highly efficient use of solar light/thermal energy that will contribute to the realization of a sustainable energy society. To understand the unique physical properties of these materials from the fundamental principles and extract superior functions that exceed the limits of conventional materials, we are promoting interdisciplinary research that covers basic sciences, including condensed matter physics and materials synthesis, as well as thermal, mechanical, electronic, and optical engineering along with the fabrication of integrated materials.

#### 1) Highly-efficient solar energy conversion application of carbon nanotube's quantum thermal optical properties

In various engineering fields, properties of available materials determine the physical limits of implementable functions. Thus, the emergence of new material systems with unconventional physical properties may bring innovation to various fields including energy science. To find the seeds of this innovation, it is necessary to accumulate basic research on novel physical properties and link the results to the future development of energy science and technology.

As a part of such efforts, we have been developing an innovative solar energy spectrum converter by introducing the latest findings that we have discovered in CNT—generation of narrow-band exciton thermal radiation in high-temperature CNT—to the engineering of thermal radiation control. This research aims to convert broadband solar energy into narrow-band energy with high efficiency and apply it to future solar energy utilization technologies, such as highly efficient solar



Quantum thermal-photophysical properties of carbon nanotubes and their applications.

Narrow-band thermal exciton emission spectra of semiconducting carbon nanotubes at about 1500 K (left) and schematic of solar energy spectral conversion using the excitonic thermal radiation of a carbon nanotube assembly film (right).

thermal power generation, solar steam generation, and solar thermal material synthesis.

#### 2) Integrated functional nanomaterials for energy applications

When nanomaterials are integrated for use in macroscale engineering, interactions among each component material often cause significant changes in their physical properties. Thus, understanding the physical properties of the individual nanomaterial alone is not sufficient to accurately predict as well as design the physical properties and functions of macroscopic assembly of nanomaterials for their use in engineering. In addition, it is relevant to elucidate the physical properties and functions that emerge in the macroscopic assembly for the design and property control of integrated materials in which nanomaterials are used as building blocks. We are working on the creation of highly functional and high-value-added nanocarbon-integrated materials, such as single chiral structure nanotube assembly and nanotube composites with excellent optical, thermal, electronic, and mechanical properties. This study aims at their applications to high-efficiency solar energy utilization technology, high-performance thermal management materials, and ultrahigh specific strength materials for extremely fuel-efficient transportation machinery. Further, to develop expensive high-performance nanocarbon materials into low-cost materials that can be used ubiquitously on a global scale, we will promote comprehensive studies such as developing technologies for sustainable procurement of raw materials and energy required for their synthesis.

#### 3) Development of unconventional infrared photoelectric conversion device using quantum materials

We are studying new methods for the synthesis and growth of quantum materials, as well as exploring novel physical properties and functions of such materials to realize high-performance energy conversion technologies that can surpass the physical limits posed by conventional materials. As a research infrastructure for this purpose, our laboratory is equipped with crystal growth systems of various quantum materials and advanced physical property measurement facilities that can perform various spectroscopic measurements, such as time-domain, frequency-domain, spatially-resolved, polarization-resolved, and micro-current measurements on microscopic samples in a wide temperature range. As a part of the research using such facilities, we are studying infrared photoelectric conversion phenomena due to the unconventional mechanism in topological quantum materials. Ultimately, we aim to develop an efficient direct photoelectric conversion technique for mid-infrared thermal radiation from heat sources such as industrial waste heat, geothermal heat, and domestic waste heat.



Synthesis and assembly of various quantum materials



Broadband optical property measurement systems

## Advanced Laser Science Research Section

The use of lasers enables us to provide energy to the target materials and monitor their real-time change without any physical contact. We fully utilize such properties of lasers to synthesize nanomaterials and carry out the real-time monitoring of their dynamics.



Associate Professor  
Takashi Nakajima

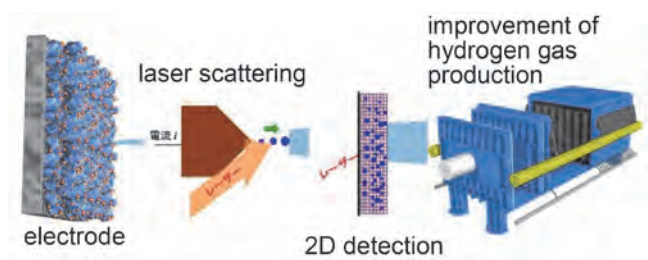


Program-Specific  
Assistant Professor  
Kota Ando

Professor (Concurrent)  
Yuhei Miyauchi

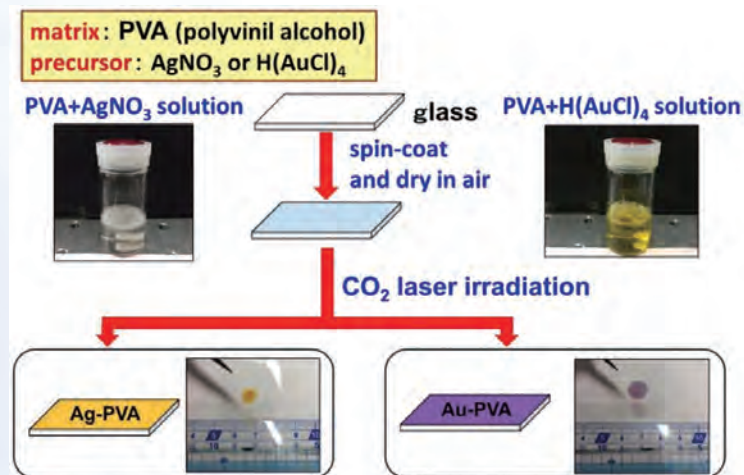
### In-situ synthesis and real-time analysis of nanomaterials using lasers

Typical strategies to modify the film properties are to introduce a multilayer structure or nanoparticles in the film matrix. Our aim is to develop a new technique to in-situ synthesize nanoparticles in the film matrix using a laser, and utilize them for new optical devices. Another important subject we are working on is to develop a new optical technique to monitor the formation of nanobubbles during the electrolysis with an aim to improve the efficiency of water electrolysis for the efficient production of hydrogen gas.



#### Optical detection of bubbles during electrolysis

By clarifying the formation process of hydrogen bubbles during the water electrolysis by laser scattering technique we can design better electrodes with optimized morphology.



#### In-situ synthesis of polymer-metal nanocomposite film

By irradiating a CO<sub>2</sub> laser at 1 W for 10 sec the polymer film with a precursor of nanoparticles turns into nanocomposite films.

# Advanced Energy Structural Materials Research Section

Innovative structural materials R&D with focusing on nanomeso structural control, and basic research for understanding materials performance and behavior



Associate Professor  
Kazunori Morishita

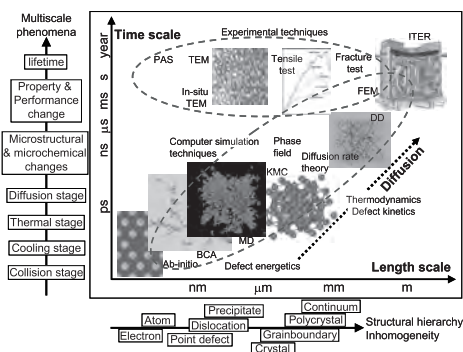


Assistant Professor  
Kiyohiro Yabuuchi

Professor (Concurrent)  
Yuhei Miyauchi

## Multiscale Modeling of Irradiation Processes of Fusion Materials

Many international programs are being underway for developing nuclear fusion reactors, which are one of the promising earth-friendly candidates for future energy sources. Material's issues are of critical importance, because reactors' integrity is basically determined by the component materials that suffer from severe irradiations. For developing irradiation-resistant materials, the database on materials' behavior during irradiation is required. However, they should reluctantly be obtained using the alternative, existing irradiation facilities such as fission reactors and ion accelerators, because of no actual fusion reactors at present. To overcome the difficulties caused by the difference between the two environments, a methodology to predict material's behavior in the actual environment using the existing materials' data is required. Our efforts have been made to establish the methodology. Molecular dynamics, kinetic Monte-Carlo, ab-initio calculations, and rate-theory equations are powerful tools to understand radiation damage processes, which occur at a wide variety of time and length scales.



### Multiscale radiation damage process

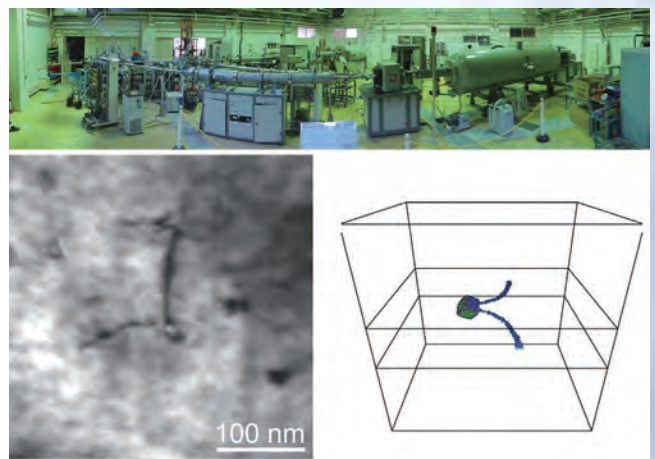
Radiation damage processes show different behavior depending on time and length-scales that you are observing. To understand these multiscale phenomena, various investigation methods using computer simulations and experiments should complementarily be employed.

## R&D of fusion reactor materials

We study the materials for divertor and blanket to realize fusion reactor. It is essential for fusion reactor to develop plasma facing material. Plasma facing material is used under the high heat flux and high energy particle irradiation such as neutron. Especially, the property degradation due to the high energy particle irradiation (irradiation embrittlement) is one of the most important issues for lifetime of fusion blanket. It is required to predict the degradation for the design and economy. We study the irradiation embrittlement using an ion accelerator, DuET. DuET has two beam line, heavy ion beam and He ion beam, and it enable the irradiation experiment under the condition close to the fusion reactor. We join various domestic and international project to realize the fusion reactor.

## Fundamental study for materials science

Lattice defects play an important role in the various issues and property changes in materials. Ion accelerator has been well known as the way to induce oversaturation point defects into materials and has contributed to the development of materials science. We study on the point defects in materials using the ion accelerator to elucidate the fundamental theory of materials science. Moreover, we develop the materials with higher or new properties by nano-meso microstructure control.



The interaction between vacancy cluster induced by ion accelerator and a dislocation: comparison between experimental study and computational study.

## Nano Optical Science Research Section

We are studying about development of novel optical physics and its application for energy conversion based on nano-science from the viewpoint of solid state physics, material science, and device engineering.



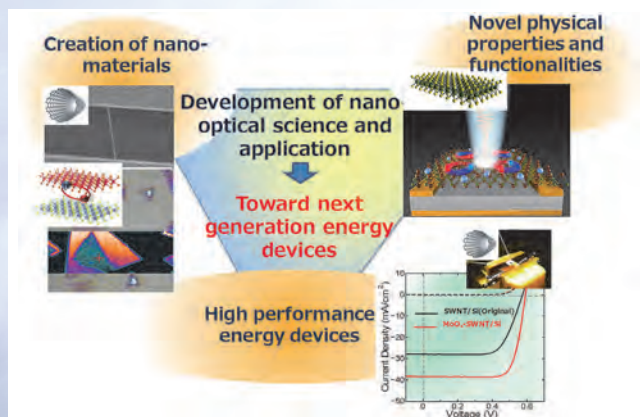
Professor  
Kazunari Matsuda



Assistant Professor  
Keisuke Shinokita

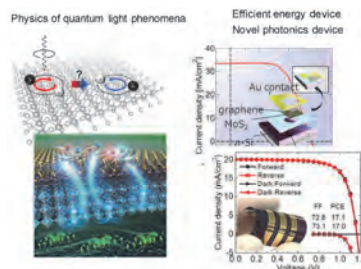
### Development of Novel Optical Physics and its Application for Energy Conversion

Research objectives in our group are “development of novel optical physics and its application based on nano-science for energy generation and conversion”. We are trying to open new horizon on the energy science by introduction of nano-materials, quantum optical physics, and device application. The understanding of physics of emerging quantum optical phenomena in extreme low-dimensional materials are important issues toward next generation light energy sciences.



### 1) Photophysics and Applications of Nanomaterials

In the nano-meter size materials (nano-material), the novel electronic and optical properties are emerged by quantum effect of electronic systems. Our research focuses on photo-physical properties and applications of nanomaterials including carbon nanotubes, graphene, and atomically thin semiconductors in which distinct quantum effects dominate their physical properties. We make use of advanced optical spectroscopic techniques to clarify the physical properties of nanomaterials for developing novel energy-efficient devices.

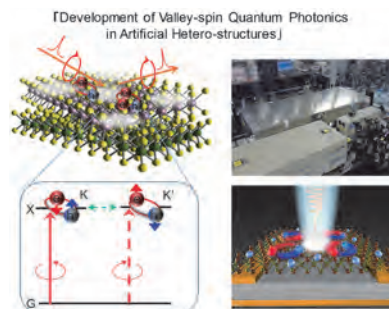


Physics in quantum light phenomena, and application for novel energy devices.

(Left) Schematic of valley-spin polarized exciton dynamics in atomically thin materials and novel excitonic states in their artificial hetero-structures. (Right) Novel energy conversion device based on atomically thin semiconductors and graphene. Flexible solar cell device using the organic-inorganic perovskite materials.

### 2) Novel Photonics Based on Atomically Thin Materials

Atomically thin-layered material including graphene comprising from monolayer carbon atoms has attracted much interest for both fundamental research and practical application because of exotic quantum states. In the atomically thin materials, the strong coupling of valley and spin degree of freedom induces novel physical degree of freedom as “valley-spin” in monolayer two dimensional transition metal dichalcogenides ( $MX_2$ ;  $M=Mo, W, X=S, Se, Te$ ). Recently, we found the new route for valley-spin quantum optics through the series of studies by quantum control of valley-spin states, revealed by femtosecond ultrafast spectroscopy and field effect transistor (FET) device. Thus, we would like to develop the new field of valley-spin quantum photonics providing great impacts on the optical and material science research. Moreover, we extend these fundamental studies to application of valley-spin quantum photonics.



Development of valley-spin quantum photonics in artificial hetero-structure.

(Left) Schematic of quantum control of valley-spin polarized states in artificial hetero-structure. (Right) Experimental setup of state of art femtosecond spectroscopy and device structure for valley-spin quantum optics.



## Chemical Reaction Complex Processes Research Section

We are studying materials and systems to realize renewable energies like photovoltaics and bioenergy as the major primary energy source for human beings. We are conducting innovative researches that cover the phases from basic research to applications mainly based on electrochemistry and biochemistry.



Professor  
Toshiyuki Nohira



Program-Specific  
Associate Professor  
Kenji Kawaguchi



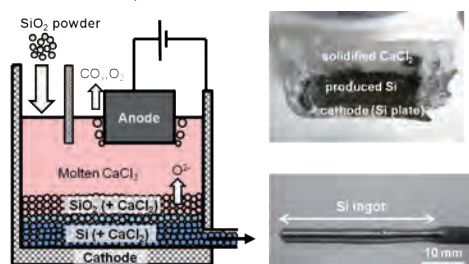
Assistant Professor  
Takayuki Yamamoto



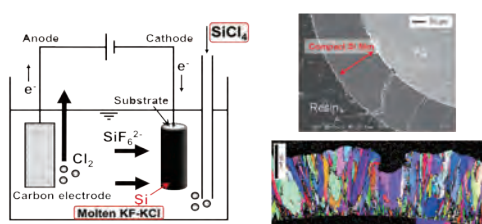
Assistant Professor  
Yutaro Norikawa

### Development of new production processes for solar silicon utilizing molten salt electrolysis

Crystalline silicon solar cells are the most spreading in the world owing to the advantages of high efficiency, high durability, harmlessness for the environment, and abundant resources. Naturally, they are expected to play a major role in the era of full-fledged dissemination of solar cells. However, high purity silicon (or solar-grade silicon, 6N purity), which is necessary for the solar cells, is currently produced by a similar method that was developed for the production of semiconductor-grade silicon (11N purity). A new production method of solar-grade silicon is required because the conventional production method has the disadvantages of low energy efficiency, low productivity, and high cost. From this background, we have proposed a new production method of silicon from the purified silica ( $\text{SiO}_2$ ) feedstock by using molten salt electrolysis. We have already verified the principle of the method, and are now tackling the development of continuous electrolysis process and the improvement of purity. Also, we have proposed a new production method of crystalline silicon film by molten salt electroplating. For this method, we have already confirmed the principle as well. We are now taking on the improvement of film quality and the utilization of  $\text{SiCl}_4$  as a silicon source.



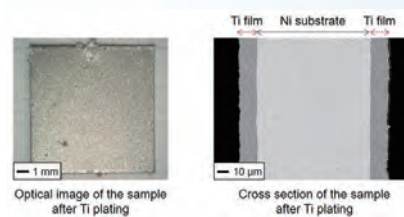
A new production method of solar-grade silicon by the electrochemical reduction of silica in molten salt



A new production method of silicon films for solar cells by the molten salt electroplating

### Development of Plating Process of Titanium Utilizing Molten Salt Electrolysis

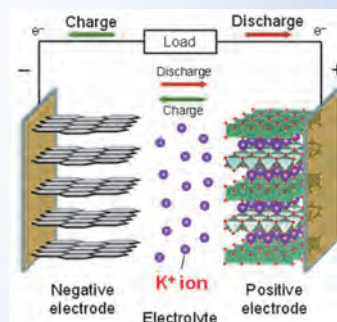
To utilize surface properties of titanium and its alloys, a method to form a titanium film on the substrate has shown great promise. We are developing a plating method in molten salt as a method that enables uniform titanium deposition even on substrates with complex shapes.



Obtained Ti films with smooth surface by the molten salt electroplating

### Development of next-generation batteries using highly-safe ionic liquid electrolytes

Renewable energy resources such as solar and wind power are intermittent resources, and their power generations are largely dependent on the weather. Thus, introduction of a large amount of renewable energy requires large-scale power storage systems such as large-sized batteries. Although current lithium-ion batteries are candidates for large-sized batteries, scarce resources (lithium, cobalt) and flammable electrolytes (organic solvents) are used as main components, which will be a major barrier for the widespread distribution in the future. Therefore, we are now developing next-generation batteries utilizing abundant resources (sodium, potassium, etc.) and safer electrolytes (ionic liquids).



Principle of potassium-ion battery

## Molecular Nanotechnology Research Section

Nanoscience and technology, ultimate method for producing new materials assembling from single molecules, are studied for energy sector such as organic transistors and solar cells.



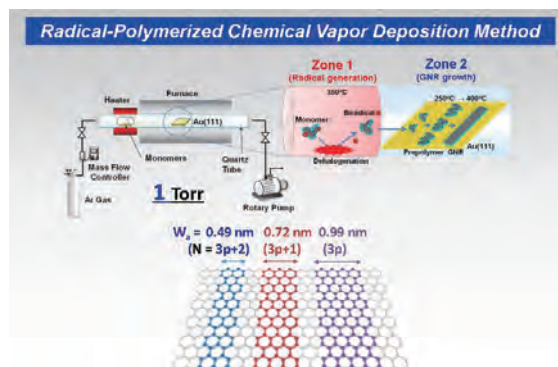
Professor  
Hiroshi Sakaguchi



Assistant Professor  
Takahiro Kojima



Assistant Professor  
Shunpei Nobusue

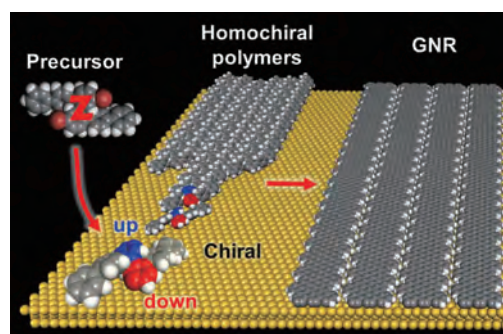


### Bottom-up synthesis of graphene nanoribbons

Extremely narrow carbon wires developed by our bottom-up surface synthesis technique.

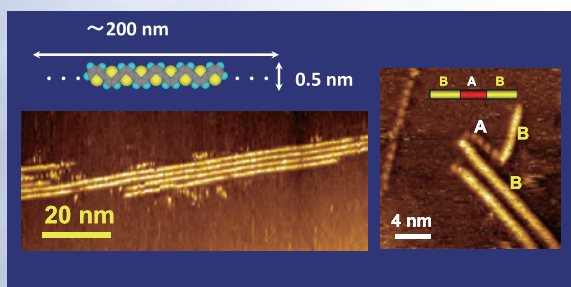
### Nanoscience and technology using single molecules

Nanoscience and technology, ultimate techniques for producing new materials assembling from single molecules, are desired to apply in energy sector. Highly efficient devices such as field-effect transistors, solar cells, batteries could be realized by using nanotechnology. We have developed "Electrochemical Epitaxial Polymerization" technique which is a totally new molecular assembling technique of molecular wires on metal surface from single molecules using intense electric field at solid- solution interface (electric double layer). Also, "radical-polymerized chemical vapor deposition" technique which is totally new method to produce graphene nanoribbons using high concentration of monomer radicals at interface between substrate and gas has been developed. Unprecedented molecular-wire materials consisting of carbon for energy usage will be developed by the use of these techniques. Polycyclic aromatic hydrocarbon molecules for a monomer of molecular wire and for molecular electronics will be synthesized using our new methodology. Organic electronic devices such as field effect transistors, photovoltaics, batteries and photocatalysis will be developed using our new techniques.



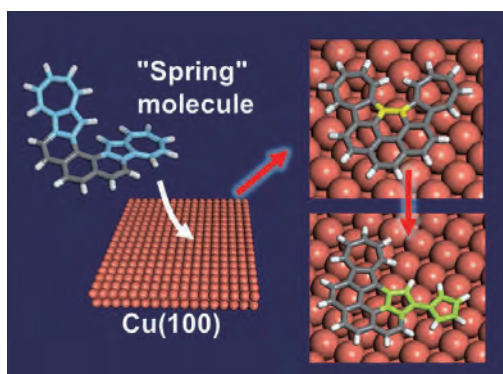
### Bio-mimetic surface synthesis of graphene nanoribbons

GNRs can be produced by bio-mimetic principles consisting of chiral transformation, of designed z-bar-linkage precursors, self-assembly, homochiral polymerization and dehydrogenation.



### Conducting polymer wires array

Conducting polymer wires array on metal surface by the use of 'Electrochemical Epitaxial Polymerization' technique.



### Strain-induced skeleton rearrangement of hydrocarbon molecules on surface

Designed spring molecules on Cu surface can be transformed into the functional fluvalene skeleton.

# Biofunctional Chemistry Research Section

Our research group is exploring the design and the construction of biomacromolecules "tailored" for pursuing highly efficient energy utilization.



Professor  
Takashi Morii



Associate Professor  
Eiji Nakata

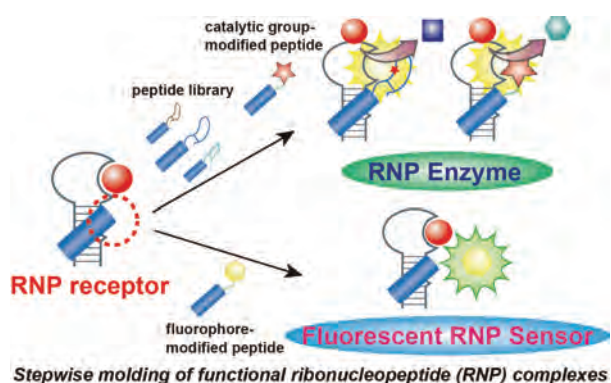


Assistant Professor  
Peng Lin

## A design principle of functional biomolecules for highly effective energy utilization

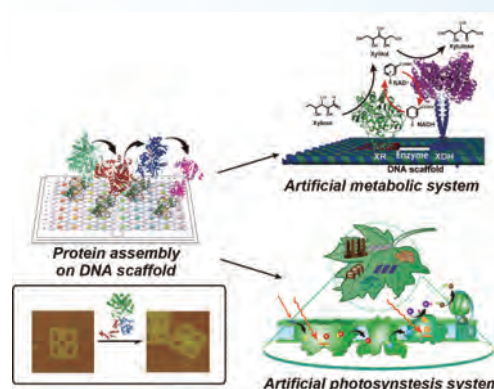
A transition to renewable energy technologies requires new chemistry to learn from nature. It is our challenge to understand the efficient bioenergetic processes of nature and to construct human-engineered energy utilization systems. The research interests in our group focus on the design and assembly of biomacromolecules for energy conversion, catalysis and signal transduction in water, the solvent of life.

We take synthetic, organic chemical, biochemical and biophysical approaches to understand the biological molecular recognition and chemical reactions. Miniature proteins and protein/nucleic acids assemblies are explored to construct artificial biomimetic devices mimicking the function of biological systems and imaging cellular signals by fluorescent biosensors. New biomolecular assemblies are designed to realize artificial receptors and enzymes based on the complex of RNA and protein, and artificial metabolic systems for useful chemicals.



Exploring functional biomacromolecules by using RNP complexes.

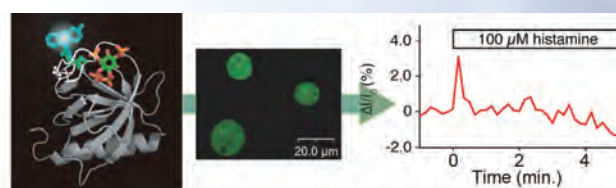
Design strategies to tailor receptors, sensors and enzymes are explored by utilizing structurally well-defined protein-RNA complexes. Stepwise strategies of the structure-based design, in vitro selection and the chemical modification afford highly specific receptors for biologically important ligands, such as ATP and the phosphorylated tyrosine residue within a defined amino acid sequence.



## Nanoassembly of enzymes and receptors to realize artificial metabolic systems

Cellular chemical transformation processes take place in several reaction steps, with multiple enzymes cooperating in specific fashion to catalyze sequential steps of chemical transformations. One of the most popular natural systems is photosynthesis system. Such natural systems are effectively reconstructed in vitro when the individual enzymes are placed in their correct relative orientations.

DNA nano-structure such as DNA-origami can be used as "molecular switchboards" to arrange enzymes and other proteins with nanometer-scale precision. A new method was developed based on proteins, to locate specific proteins by means of special "adapters" known as DNA binding proteins. Several different adapters carrying different proteins can bind independently to defined locations on this type of nanostructure. By using the system, nanoassembly of enzymes and receptors will be constructed as the multi-enzymatic reaction system to realize artificial metabolic systems.



## Real-time fluorescent monitoring of $IP_3$ production in the single cells

Exploring functional biomacromolecules by using RNP complexes.

Structure-based design provides an alternative strategy to construct protein-based biosensors that assess intracellular dynamics of second messengers and metabolites.

# Structural Energy Bioscience Research Section

We aim at the establishment of biorefinery through the development of biomass and biomolecules based on structural biology.



Professor  
Masato Katahira



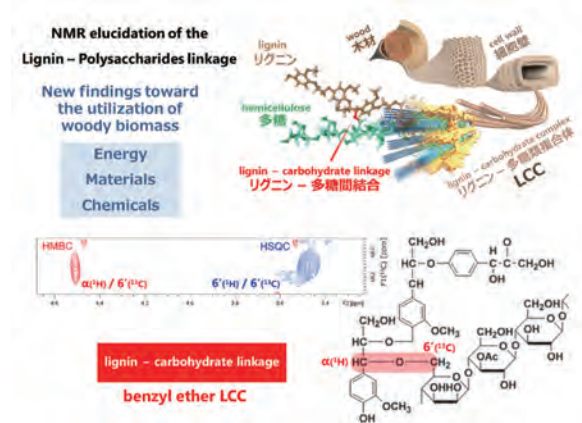
Associate Professor  
Takashi Nagata



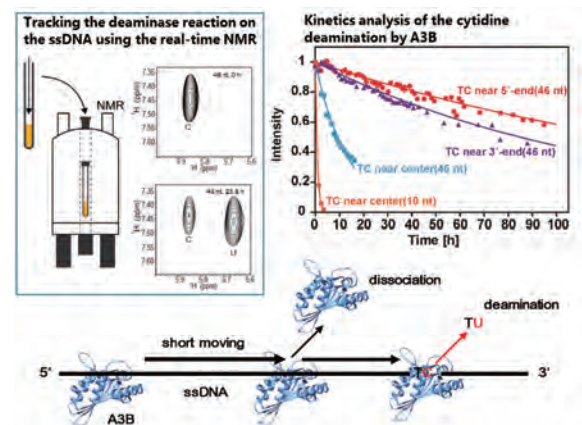
Assistant Professor  
Yudai Yamaoki

## Toward biorefinery through the development of biomass and biomolecules based on structural biology

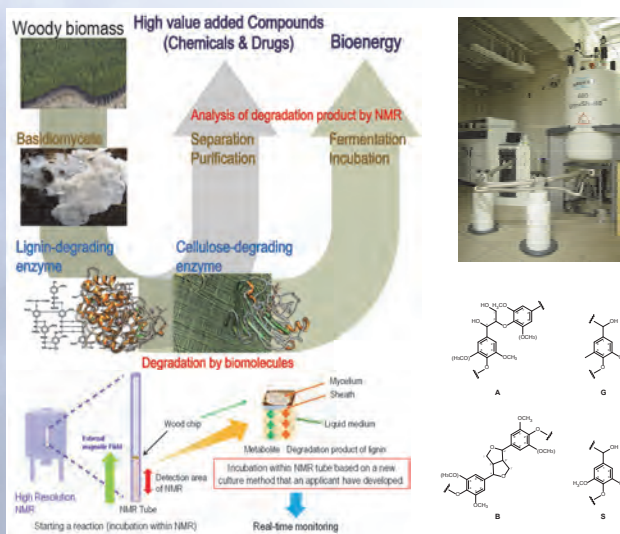
We explore the way how biomolecules such as proteins (involving enzymes) and functional nucleic acids (DNA and RNA) work at atomic resolution based on structural biology with NMR. For example, we have elucidated how functional RNA can trap the protein that causes prion diseases. We are also engaged in development of the new methodology to elucidate the underlying mechanism of functions of these biomolecules. We have successfully developed the way to monitor the base conversion reaction by anti-HIV enzyme in real-time by NMR for the first time. Currently, we are developing the way to extract energy and valuable materials that can be used as starting materials of various products from wood biomass. Thus, we pursue to contribute to the paradigm shift from oil refinery to biorefinery.



Obtained the direct evidence of the lignin-carbohydrate linkage in wood cell walls by the heteronuclear multidimensional NMR techniques

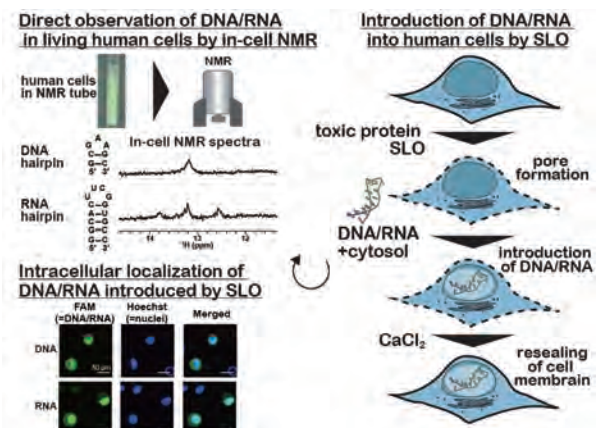


The real-time NMR observation of the ssDNA-specific cytidine-deaminase activity of APOBEC3B



Biorefinery based on biodegradation of woody biomass studied by NMR

Establishment of biorefinery on the basis of biodegradation of wood biomass studied by NMR



Observation of the in-cell NMR signals of the hairpin structure forming DNAs and RNAs introduced inside the living human cells

## Self-Assembly Science Research Section

The aim of this research is to construct the supramolecular assemblies of the topologically interlocked components inside a DNA origami. Such assemblies of the functional structures are promising in the fields of molecular switches, motors, sensors, and logic devices.



Junior Associate Professor  
Arivazhagan Rajendran

Professor (Concurrent)  
Takashi Morii

### Nanomolecular fabrication of supramolecular assemblies

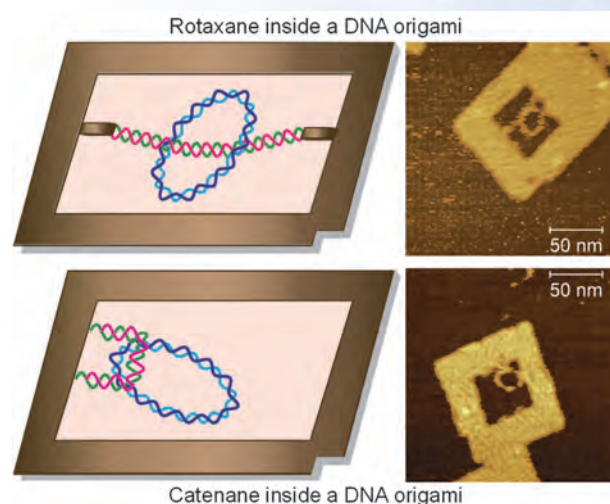
DNA molecules are not merely associated with genetics and the carrying of information. They have been used as excellent construction units in structural DNA nanotechnology due to their unique structural motifs and robust physicochemical properties. I have been working on the self-assembly of DNA origami (a method to create nanostructures by folding DNA) nanostructures to create micrometer scale structures that can be used for several applications such as fabrication of nanodevices, analysis of biomolecular reactions, and templates for various applications. Also, I have utilized these nanostructures for the single molecule analysis of various biomolecular reactions, structure and function of DNA and proteins, and enzymes related to biomass energy conversion.

Recently, I have been collaborating with the research groups of Prof. Takashi Morii (IAE, Kyoto University) and Prof. Youngjoo Kwon (Ewha Womans University) for the nanofabrication of the topologically interlocked supramolecular assemblies. Topologically interesting structures such as Borromean rings, catenanes, rotaxanes, and knots have been prepared by using duplex DNAs. Also, the complexity of the catenane and rotaxane structures were increased by constructing them by the DNA origami method. However, integration of the duplex DNA catenanes and rotaxanes with functional sequences to the relatively larger and complex DNA nanostructures such as DNA origami has not yet been realized. We have successfully fabricated the DNA catenane and rotaxane structures inside a frame-shaped DNA origami. Apart from the applications in nanotechnology, these interlocked structures can be used for the biomolecular analysis, such as enzymatic reactions and drug screening. For example, these topological structures can be used as the potential substrates for the topoisomerase (Topos) enzymes, and screening of Topo inhibitors.

Among the various types of DNA-binding proteins, Topos are quite attractive due to their importance in cancer therapy. Topos regulate the topological problems of DNA that arises due to the intertwined nature of the double helical structure. These enzymes also play an important role in various biological processes such as replication, transcription, recombination, and

chromosome condensation and segregation. Topos resolve the topological problems by transiently cleaving the phosphodiester bond, which generates a Topo-DNA cleavage complex. Once the winding stress is resolved, the Topo-mediated DNA break is resealed. This process is critical for the healthy cells to survive and function normally. Failure to reseat the DNA break can ultimately lead to cell death. This Topo-DNA cleavage complex and various other steps (such as binding of Topo to DNA, ATP driven strand passage, strand cleavage by Topo, formation of Topo-DNA cleavage complex, religation of cleaved DNA, and catalytic cycle after DNA cleavage/enzyme turnover) involved in the Topos function are of great interest as potential targets for the development of anticancer drugs. Despite the development of various Topo-inhibitors, the mechanism of action of these anticancer drug molecules is not well known. Thus, to understand the Topos reaction and the mechanism of the inhibitors, it is necessary to develop an elegant method.

Here, we aim to develop a novel method by using our supramolecular assemblies of the catenane and rotaxane inside a DNA origami and high-speed atomic force microscopy (HS-AFM) for the screening of Topo-inhibitors. The formation of the DNA origami frame and the insertion of the catenane and rotaxane structures were characterized. The Topo reactions and the function of Topo-inhibitors are under investigation. Apart from the Topo reactions and inhibitor screening, the supramolecular assemblies of the topologically interlocked components inside a DNA origami are also promising in the fields of molecular switches, motors, sensors, and logic devices.



**DNA rotaxane and catenane inside a DNA origami frame**  
Left: The illustration of the topologically interlocked DNA rotaxane and catenane inside a DNA origami frame. Right: AFM images of the respective structures.

## Environmental Microbiology Research Section (Donation Program)

Energy issues and environmental issues are inseparable. We are still highly dependent on fossil energy, and there is concern that discharged greenhouse gases will break the harmony of global environment. In addition, we need large amount of energy to remediate an environmental pollution that remains the shadow of the progress of civilization with fossil fuel energy consumption. As one of the creating methods for sustainable society, we confront the development of practical applications utilizing "enzymes" that are highly energy utilization efficiency in substance catabolism.



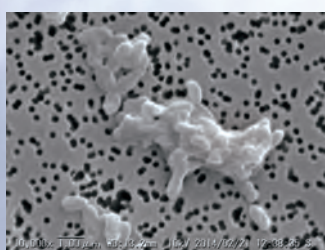
Program-Specific Professor  
Tomijiro Hara



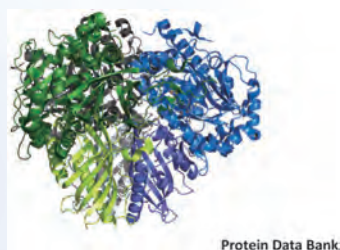
Program-Specific Associate Professor  
Yumiko Takatsuka

### Establish an optimal process utilizing the oxidation-reduction reactions of enzymes for advanced environmental remediation

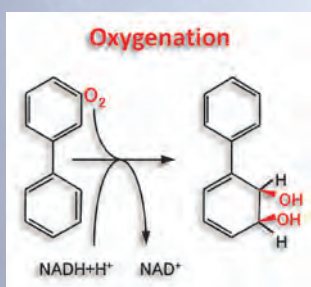
Polychlorinated biphenyls (PCBs) are organochlorine compounds containing theoretically 209 homologs of various chlorine substituents, and it had used in various industrial applications as "dream substance". However, PCBs has been already promoted globally abolition of the usage and the manufacturing since it was proven human endocrine disruptor. Biphenyl dioxygenase (BDO) plays a crucial role for degradation of PCBs. BDO catalyzes incorporation of two oxygen atoms into the aromatic ring of PCBs, and it induces the ring cleavage. We developed the composite type of catalytic enzymes with two BDOs that having different substrate specificity and the bioreactor for generating oxygen microbubbles that enhancing the enzymatic activity of BDOs. As the result, we succeeded constructing the practical system using both the catalytic enzyme and the microbubbles that degraded over 99% of 40 mg L<sup>-1</sup> commercial PCBs in 24 hours. In order to expanding this composite degradable reaction of PCBs, we are trying to create unique artificial enzymes, which reduce PCB by two-electron reduction.



A. Scanning Electron Microscope image of *Comamonas testosteroni* YAZ2 strain which produce biphenyl dioxygenase (BDO). This strain is gram negative and rod-shaped bacterium. Magnification is ×10,000. Scale-bar is 1 μm.



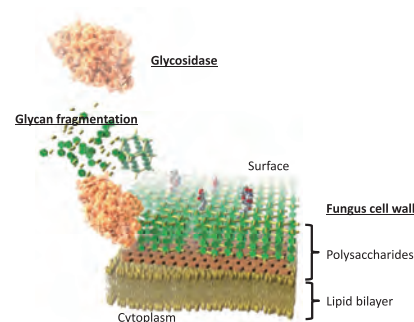
B. Molecular structure model of BDO which catalyze oxygenation reaction toward PCBs (Ref: PDB).



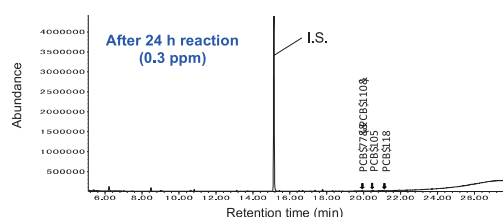
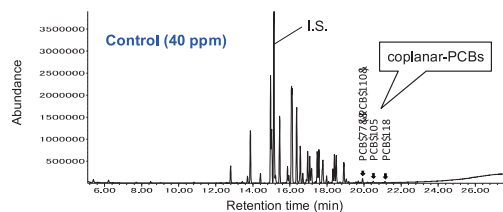
C. Enzymatic reaction showing how BDO hydroxylates one aromatic ring by adding oxygen to biphenyl.



E. Morphological study of *Trichoderma viride* MAFF 30546 strain which was treated by enzyme(s) (right) compared with the control (left). Enzyme reaction was carried out at 30°C for 6 hours. *Trichoderma viride* MAFF 30546 strain was stained with lactophenol cotton blue. Magnification is ×400. Scale bar is 50 μm.



F. Image showing how glycosidase digests fungus cell walls.



D. The result of reacting 40 mg L<sup>-1</sup> of commercial PCBs with composite type of catalytic enzyme, it degraded to 0.3 mg L<sup>-1</sup> in comparison with the control (top) within 24 hours (bottom). PCBs was analyzed by gas chromatograph quadrupole mass spectrometer.

### Establish an optimal plant disease control methods utilizing enzymatically reaction for an organic food production

Many of plant diseases are generally caused by either ascomycetes or basidiomycetes that belonging to filamentous fungi. "Filamentous fungi" is hypha, and it is proliferated to mycelia. The cell wall is engineered as a composite material. It incorporates a mix of cross-linked fibers and matrix components. The fibrous components of cell wall are glucan, chitin, and mannan, and these sugarchains contribute forming a supple and solid filiform microfibril wall. Glycosidase is one of the hydrolases that catalyzes the hydrolysis of glycosidic bonds in complex sugars. We develop a new bio-molecular type of fungicide utilizing the hydrolysis reaction of glycosidase against fungal microfibril wall. Up to now, our composite type of bacterial catalyst composed of 5 strains from class Bacilli, which produce and secrete various glycosidases, controlled 99.3% of a tomato- *Pestalotia* disease with *Pestalotiopsis* sp. Glycosidases are classified into approximately 130 families, and its catalytic reaction is roughly divided into anomeric-inversion and/or anomeric-retention, and exoglycosidase or endglycosidase. Hence, the classification of glycosidase can be understood diverse, and we consider that it is possible to digest fungi cell wall efficiently, by compositely capably using these diversities of enzyme reactivity.

# Biomass Product Tree Industry-Academia Collaborative Research Laboratory

We aim at the development of new conversion process and sustainable circular use of biomass.

Professor (Concurrent)  
Masato Katahira

## Determination of Fine Structure by NMR and Development of Utilization Using Enzymes of Biomass

Kyoto University and Daicel Ltd. have been carrying out collaboration aiming at realization of circular-type low-carbon society and development of industries. We have contracted the comprehensive cooperation agreement on October 1, 2021. The contract will stand for eight and half a year until 2030. Our Institute has started "Biomass Product Tree Industry-Academia Collaborative Research Laboratory" in collaboration with Research Institute for Sustainable Humanosphere, Institute for Chemical Research and Daicel Ltd. Professor Katahira's group participates in the Collaborative Laboratory with the research theme of "Determination of Fine Structure by NMR and Development of Utilization Using Enzymes of Biomass".

Currently, sixteen members are engaged in the Collaborative Laboratory.



Discovery of the enzyme LPMO that dramatically enhances the breakdown of cellulose in collaboration with cellulases and elucidation of the operation mechanism.

(Left) Enhancement of the breakdown of cellulose by the combinatorial use of LPMO and cellulases. (Right) Molecular structure of LPMO in action of breaking down of cellulose.

## Adjunct Faculty Members

▶ Advanced Energy Conversion Division Clean Energy Research Section



Visiting Professor

**Kenji Kitayama**

Biomass Innovation Center, Daicel Corporation, Senior Research Scientist

Dr. Kenji Kitayama completed the master's course at the Department of Synthetic Chemistry, Graduate School of Engineering, Kyoto University in 1992. Completed the doctoral course at the Department of Pharmaceutical Chemistry, Graduate School of Pharmaceutical Sciences, Hokkaido University in 1996, Ph.D. (Pharmacy). He joined Daicel Chemical Industries Co., Ltd. in April of the same year. From July 2017, Senior Research Scientist, Research and Development Center, Organic Chemical Products Company. April 2020-Research Center Senior Research Scientist. He has been in his current position since April 2022.

Academic Society Position: May 2020-May 2022, Director of the Chemical Society of Japan (specialty).

Specialty: Synthetic Organic Chemistry, Organometallic Chemistry, Catalytic Science, Forest Chemistry.

At the same time as signing a comprehensive collaboration agreement with Kyoto University in October 2021, Daicel established an industry-academia collaborative research laboratory in the Uji area as a base for fusion of research fields and industry-government-academia collaboration. We are advancing research to establish a technology for dissolving wood under mild conditions of normal temperature and atmospheric pressure, and to lead to the development of high-performance products. If we can easily dissolve biomass resources, it is expected that the efficiency of chemical conversion and molding will increase, leading to an industry that does not rely on petroleum. We call this business concept of dissolving under mild conditions and converting it into a high-performance material, "the biomass product tree".

Key words: biomass resources, carbon neutral, materials development

▶ Advanced Energy Conversion Division Clean Energy Research Section



Visiting Associate Professor

**Shigeru Kashiwagi**

Research Center for Electron-Photon Science, Tohoku University (Accelerator and Beam Physics), Associate Professor

Dr. Shigeru Kashiwagi received his PhD from The Graduate University for Advanced Studies, SOKENDAI in 1999. He spent four years at Waseda University as a Visiting Researcher. In 2003, he moved to Osaka University as an Assistant professor. In 2010, he moved to Tohoku University as an Associate Professor and to the present.

His field of research is Accelerator and Beam Physics mainly on the electron accelerators. In particular, the research is being conducted on the generation mechanism and polarization / amplitude control of a coherent radiation from extremely short electron beams. At the test accelerator (t-ACTS) at Tohoku University and the KU-FEL facility at Kyoto University, a coherent undulator radiation source in the THz region using short electron pulses is being developed. THz waves have traditionally been used as probes for characterization, or spectroscopic means for "observation". High-field THz waves from the short electron pulses allow "control" of the molecular arrangement.

## The Laboratory for Complex Energy Processes

This Laboratory is a core research center for strategic and multidisciplinary collaboration studies in IAE, offering cooperative project activities in the field of the advanced energy. The Center has three divisions: (1) "Division of Plasma and Quantum Energy Research", for fusion and related advanced energy studies, (2) "Soft Energy Science Research", that promotes innovative functional materials based on nanotechnology and biotechnology, and (3) "Division of International and Industrial Partnership" that promotes and enhances activities and relationship with foreign and domestic research partners including industry and private sector. This center provides a platform for the collaborative and ambitious research activities of the IAE in the field of advanced energy studies.

## Objectives

The project studies in the Laboratory are focused on innovative and advanced concepts on the advanced energy science for the sustainability of humankind based on the latest understanding and consideration on the energy and environmental problems. We focus our efforts on two specific priority-fields at the divisions for, (1) "Plasma and Quantum Energy Research" and (2) "Soft Energy Science Research". The multidisciplinary collaboration projects are promoted in these two fields at each division with large scale research facilities used for project oriented studies. Two sections also belong to the Laboratory. The third division is established to promote international and domestic collaborative activities with various events, by planning, arranging and supporting function with various partners including governmental institution and industries. Moreover, as activities in Kyoto University, we continue to provide human resources to lead innovative energy studies based on the experiences of 21COE and GCOE programs on energy science. Development of human resources in the advanced energy field is a major function, and as in the past in several educational projects, seminars, internship and courses are included. Bilateral Collaborative Research Program in National Institute for Fusion Science (NIFS), on the study of plasma energy is promoted under the inter-university collaboration. We pursue various types of collaborations with other partners and through these activities. Donation Program for collaboration with industry and private sector belongs to the Laboratory.

## Activities

The Laboratory organizes the cooperative research programs for the scientists from various energy-relating fields inside/outside IAE. The Laboratory also provides the functions for exchanging the scientific information among the collaboration members by organizing or supporting various kinds of symposia, seminars and events for the specific topics on the fields of energy science and technology. A number of significant results have been published from these multidisciplinary collaboration projects in the Laboratory. Also, five sections belong to the Laboratory; "Self-Assemble Science", "High-Temperature Plasma Equipment Engineering", "Broad Band Energy Science", the Donation Program "Environmental Microbiology", and "Biomass Product Tree Industry-Academia Collaborative Research Laboratory".

The Laboratory has several large-scale research facilities for the collaborations; (1) Advanced energy conversion experimental devices (Heliotron J and DuET), (2) Free electron laser (KU-FEL), (3) NMR facilities, (4) Multiscale testing and evaluation research systems (MUSTER), (5) Compact and portable inertial-electrostatic confinement (IEC) fusion neutron/proton sources, (6) System for creation and functional analysis of catalytic material, etc.



Transmission lines in the laboratory



100t crane



Motor generator



## The Major Facilities and Equipment of The Laboratory



The Laboratory is consolidating several major facilities for the research programs of the Institute of Advanced Energy. Outlines of the facilities which are described below.

- Heliotron J

In our Institute, a unique helical device Heliotron J is now in operation, which is based on a Kyoto-University original concept of "helical-axis heliotron", to investigate the high-level compatibility between (i) good plasma confinement and (ii) MHD stability in the heliotron line. This project is expected to open up a new frontier of the novel plasma parameter regime in the toroidal fusion devices. The major radius of the torus is 1.2 m and the maximum magnetic field strength is 1.5 T.

- DuET/MUSTER Facility

This facility is for fundamental research on the interaction between materials and multiple charged particles with wide range of energy levels under well-controlled irradiation conditions, as well as for R&D of innovative structural materials through the unique fabrication processes of non-equilibrium and ultra-functional materials. In order to accelerate the achievement of industrial technology innovations, the comprehensive materials/system integration studies have been performed by means of multi-scale evaluation methods covering from nano-scaled analysis to the practical size of mechanical tests.

- KU-FEL (Kyoto University Free Electron Laser)

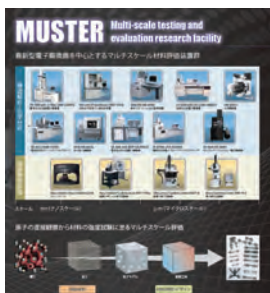
The KU-FEL provides coherent and tunable laser in Mid-IR region ranging from 3.4 to 26  $\mu\text{m}$ . The tunable IR laser has been utilized for basic study of high-efficiency solar cells, mass measurement of chemicals from biomass and selective phonon mode excitation in wide-gap semiconductors by collaboration research.

- NMR Facilities

Four NMR machines, including 800 MHz machine linked with liquid chromatography and mass spectrometer and three 600 MHz machines equipped with super-high sensitivity cryogenic probes, are operated to elucidate the three-dimensional structure and dynamics of biomass and biomolecules at atomic resolution. On the basis of the obtained knowledge, we are developing the way to extract the energy and valuable materials from the biomass and biomolecules.

- Cooperation with industries and national institute by using advanced facilities through Collaborative research office

Dual-Beam Facility for Energy Science and Technology (DuET), Multi-Scale Testing and Evaluation Research facility (MUSTER), KU-FEL, and NMR Facilities are open for industries to evaluate materials performance from the viewpoint of multi-scale structure; atomic size, defect size, grain size, etc. to understand the materials behavior in practical applications. Our facilities have supported 86 companies to contribute in their progress of innovative materials R&D.



## Cooperative Research



Besides of an inter-university collaboration program for researchers of energy relating communities, which is promoted by Joint Usage/ Research Center of Zero-Emission Energy Research, IAE, the Laboratory organizes an original cooperative research programs, "Center Collaborative Research" and "Center Sprouting Research", for IAE researchers under two divisions. The Laboratory also provides the functions for exchanging the scientific information among the collaboration members by holding various kinds of symposiums, seminars for the specific topics on the fields of energy science and technology.

# Organization of Research Projects in the Laboratory

## Division of Plasma and Quantum Energy Research

This division promotes studies on advanced plasmas and quantum energy for realizing future energy systems, integrating plasma energy science and advanced energy material research. In particular, based on the results obtained in each related group, we aim at extending the research fields and contributing to human society by utilizing the existing key devices such as Heliotron J, DuET, MUSTER and IEC (Inertial Electrostatic Confinement) device, which have been developed in IAE.

Group of advanced plasma energy control and application research	This group promotes fundamental understanding of self-regulated plasma, development of its control system, putting emphasis on generation of advanced plasma energy from experimental and theoretical viewpoints. Extension and enrichment of plasma energy application are also investigated.
Group of plasma, hydrogen, and material integration research	This group promotes the research on optimization of plasma reaction process in hydrogen cycle and understanding the mechanism of plasma-materials interactions in order to develop highly efficient and controllable energy systems.
Group of advanced energy materials- nuclear systems research	This group promotes the research on nano-meso structure control for high performance materials and materials-systems integration in order to develop innovative energy materials for advanced nuclear energy systems.

## Division of Soft Energy Science Research

This division promotes studies on emergent materials and systems for realizing next generation soft energy system. In particular, functional nano- and bio-materials to efficiently utilize solar energy and bio-energy are studied by integrating laser science and expand to THz region, nanotechnology, bio-technology and their combination. We aim at extending our research fields by utilizing the existing devices such as System for Creation and Functional Analysis of Catalytic Materials, SEMs, SPM, Solar Simulator, KU-FEL and various laser systems.

Group of nano-bioscience research	This group aims at the study on the function and the structures of bio molecules from the basic to application level. Understanding the fundamental aspects of molecular recognition, protein folding, enzymatic reactions, and the assembly formation by proteins and nucleic acids will explore a new horizon of the bio energy related nano-bioscience research, such as the development of nano-bio devices that accelerate the efficient utilization of solar energy and the biomass resources.
Group of quantum radiation and optical science research	For contributing to innovative progress in quantum radiation and photon energy science, this group aims at demonstrating potential abilities of light and radiation through the development of advanced coherent radiation sources with novel functions and their applications to materials control and photoreaction dynamics research.
Group of surface and interface science research	This group studies surface science to produce the various functional materials used in energy sector. Surface and interface of matters can be used as a template to synthesize extra-ordinal materials because of their different atomic arrays from the bulk. Research involves in semiconductor porous materials, molecular wires and organic materials for photovoltaic cells in next generation.

## Division of International and Industrial Partnership

This division promotes international collaborative research on advanced energy to lead the field of energy science and technology as an international pioneer. For this purpose, the symposium and the workshop organized by institution member are supported. This section also promotes young researcher/student exchange, cooperative research activities and multi-lateral collaborative research with industries. Establishment of infrastructure and human resource development are also supported.

Group of promotion for international collaborative research	This group promotes international collaborative research to solve global issues on advanced energy.
Group of promotion for domestic collaborative research	This group promotes domestic collaborative research to lead advanced energy science and engineering with focusing on human resource development.
Group of promotion for collaborative research with industries	This group supports research projects founded by government and/or industries to accelerate the progress in the researches with high social acceptance.
Collaborative research office	This office member supports industrial research and engineering for energy materials development and materials integration researches as an advanced project with DuET, MUSTER, KU-FEL and NMRs.

# Major Projects

A number of projects are currently underway in both scientific and engineering fields of advanced energy to realize a sustainable society that is in harmony with the environment through advanced generation, conversion, and utilization of energy.

## Inter-University Research Program (MEXT)



### Research Project for Zero-Emission Energy System

- ▶ Leader: Director of IAE
- ▶ Project Period: the 1st term: FY2011–2015  
the 2nd term: FY2016–2021  
the 3rd term: FY2022–2027

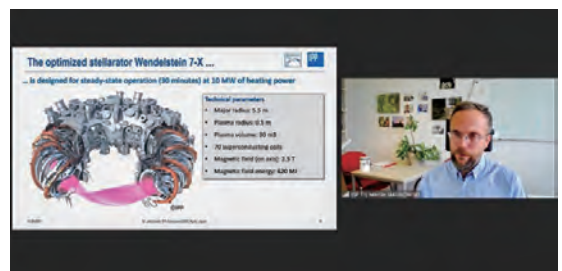
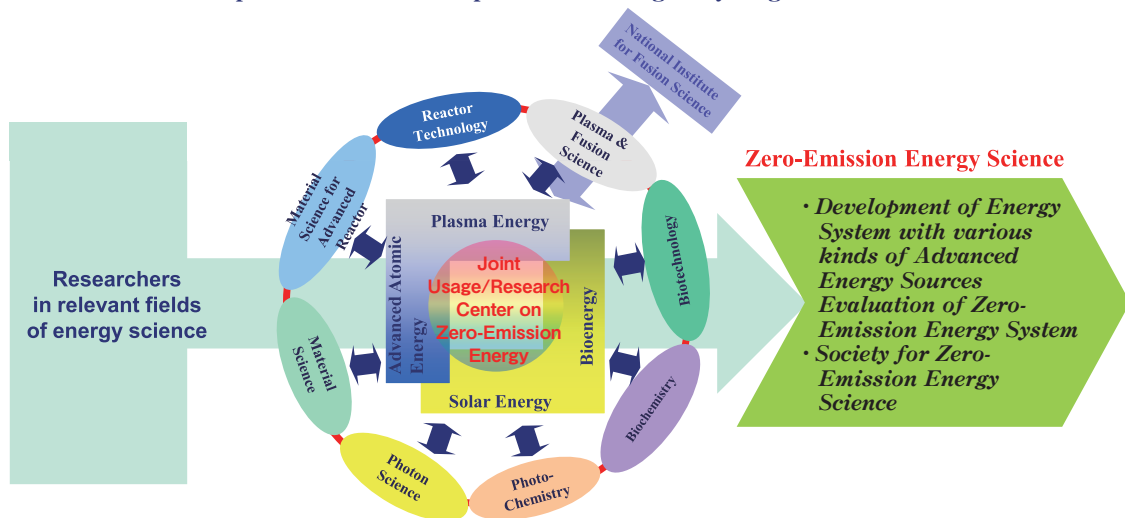
The energy system for next generation should be an environmentally friendly or ecological one, we propose an innovative concept of Zero-Emission Energy. IAE Zero-Emission Energy Research aims at the realization of environmentally friendly energy system for sustainable society with minimum emission of environmental pollutants (Greenhouse Gases, Air Pollutions, Waste Energy, Hazardous Wastes, etc.), and with maximum utilization of energy and resources. This project promotes interdisciplinary researches of energy relevant fields, education and training of young students and researchers in the field of advanced energy science. The "A" evaluation has been given at the end-of-term evaluation held in 2021 by MEXT.

#### Activities in FY2021

- Joint Usage/Research Collaborations:  
In total, 105 subjects with 600 participants from 62 organizations
- International Symposium (September 7 – 8, 2021) (on line)  
"The 12th International Symposium of Advanced Energy Science"  
– Research Activities on Zero Emission Energy Network –  
162 participants
- Zero-Emission Energy Network activities for information exchange on Zero-Emission Energy Research.
- Achievement Briefing Meeting of Collaborations in FY2021 (March 14, 2022, online).
- Promotions of other Workshops/Seminars of ZE Research.

## Joint Usage/Research Center at IAE on "Zero-Emission Energy"

- To promote interdisciplinary collaboration researches for Zero-Emission Energy Science & Technology,
- To explore new horizon of Advanced Energy System for sustainable development,
- To promote education & practical training for young researchers.

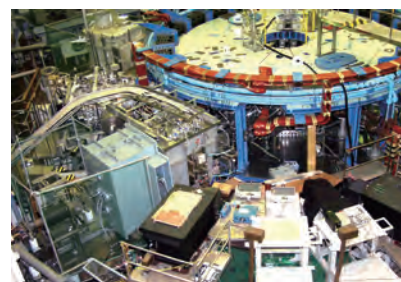


## Bilateral Collaboration Research Program (National Institutes of Natural Sciences)

▶ Leader : Prof. Kazunobu Nagasaki

▶ Project Period : FY2004 -

Bilateral collaboration research program promotes joint research bilaterally between National Institute for Fusion Science (NIFS), and the research institutes or research centers of universities that have each unique facility for nuclear fusion research. Under this collaboration scheme, the facilities are open to researchers throughout Japan as a joint-use program of NIFS. Our research subject under this program is to investigate experimentally and theoretically the transport and stability control through advanced helical-field control in the Heliotron J device.



## Grant-in-Aid for Scientific Research (S) in Ministry of Education, Culture, Sports, Science and Technology (MEXT)

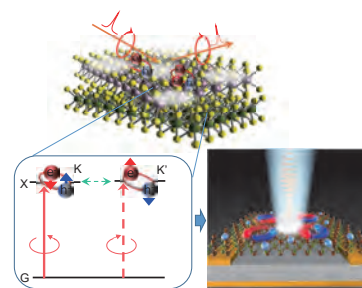
**Research area: Science and Engineering (Interdisciplinary Science and Engineering)**

**Research project: Development of valley-spin quantum photonics in artificial hetero-structures**

▶ Project Leader: Prof. Kazunari Matsuda

▶ Project Period: FY2020 - FY2024

In the atomically thin materials, the strong coupling of valley and spin degree of freedom induces novel physical degree of freedom as "valley-spin". Recently, we found the new route for valley-spin quantum optics through the series of studies by quantum control of valley-spin states. Thus, we would like to develop the new field of valley-spin quantum photonics providing the great impact on the optical and material science research. Moreover, we extend these fundamental studies to application of valley-spin quantum photonics.



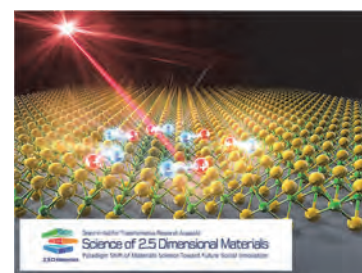
## Grant-in-Aid for Transformative Research Areas (A) in Ministry of Education, Culture, Sports, Science and Technology (MEXT)

**Research project: Development of valley-spin quantum photonics in artificial hetero-structures**

▶ Project Leader: Prof. Kazunari Matsuda

▶ Project Period: FY2021 - FY2025

In the project of "2.5 dimensional (2.5D) material science" lead by Prof. H. Ago (Kyushu University), we will develop the novel analytical methods and techniques for revealing intriguing structures and electronic properties in 2.5D materials and support the science of 2.5D materials. We provide the advanced analytical methods and techniques for the material fabrication including its assemblies and device application from its novel functionalities and play the important roles of analytical science in 2.5 dimensional (2.5D) materials.



## Strategic Basic Research Programs (CREST), Japan Science and Technology Agency (JST)

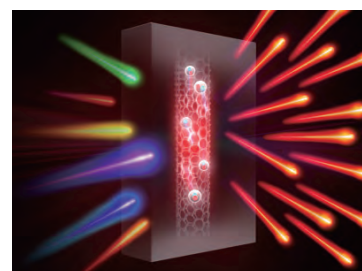
**Research area: Creation of Innovative Core Technologies for Nano-Enabled Thermal Management**

**Research project: Thermo-excitonics based on nanomaterials science**

▶ Project Leader: Prof. Yuhei Miyauchi

▶ Project Period: FY2018 - FY2023

We will study fundamental physics of the thermal exciton generation phenomenon that has recently been observed and verified in carbon nanotubes for the first time, and clarify its potential for future applications. Particularly, we will try to create a new thermal photonic technology that enables high performance solar photovoltaic conversion with efficiency beyond the standard theoretical limit, based on the thermal exciton effects and nanoscience-based thermal control technology.



Concept of thermo-excitonic photon energy conversion

## Fusion Oriented REsearch for disruptive Science and Technology (FOREST), Japan Science and Technology Agency (JST)

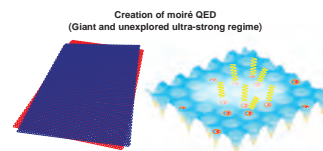
Research area: Science and Engineering (Interdisciplinary Science and Engineering)

Research project: Development of quantum electrodynamics (QED) in semiconducting moiré superlattice

▶ Project Leader : Assistant Prof. Keisuke Shinokita

▶ Project Period : FY2022 – FY2024

Quantum electrodynamics (QED) plays an essential role in controlling the quantum state of matter by light and in quantum information processing. We are developing QED in a giant quantum two-level system called a moiré superstructure and exploring a new era of QED (moiré QED). The emergent quantum optical phenomena beyond conventional cavity QED can be expected to be a breakthrough in the next generation of quantum information processing.



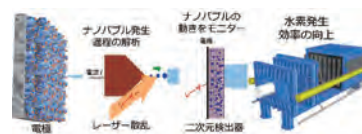
## Program for creation of new industries and new technology lead (NEDO)

Research project: Development and application of valley-spin photonics in atomically thin layered materials

▶ Project Leader in IAE: Assoc. Prof. Takashi Nakajima

▶ Project Period: FY2018 – FY2022

In recent years various kinds of renewable energies are introduced to suppress the global warming. By producing hydrogen gas through the water electrolysis with the surplus power of renewable energies, the stored hydrogen gas can be efficiently converted to the electric power at a later time as needed. In this project, we will clarify the formation mechanism of hydrogen gas bubble during the water electrolysis through the optical technique and contribute to the optimized design of electrodes and substrate materials with an appropriate pore structures.



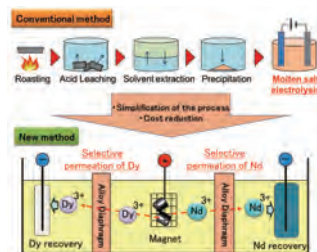
## Project to Research and Develop Recycling Technologies for Establishing a High Efficiency Resource Circulation System (NEDO)

Research and development theme: Development of high-efficiency smelting technology

▶ Sub-theme Leader: Prof. Toshiyuki Nohira

▶ Project Period: FY2017 – FY2022

We are developing a technology for the direct recovery of rare earth elements from waste materials enriched with specific rare earth elements, such as neodymium magnets, by using molten salt and alloy diaphragms. By taking advantage of the facts that a specific rare-earth-transition metal alloy phase forms at high speed and that only rare-earth ions are selectively dissolved when the formed rare-earth-transition metal alloy is positively polarized, we aim to realize an innovative rare-earth element recycling process.



## Core Research for Evolutional Science and Technology (CREST), Japan Science and Technology Agency (JST)

Research area: Elucidation of biological mechanism of extracellular fine particles and the control system

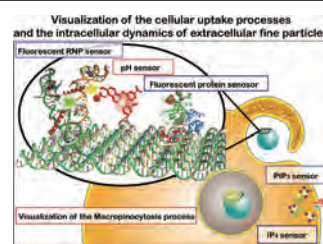
Research project: Intracellular fate of extracellular fine particles and the control system

Sub-theme: Multiple sensing system of the intracellular environment

▶ Sub-theme Leader: Prof. Takashi Morii

▶ Project Period: FY2018 – FY2023

Macropinocytosis is a central pathway to the cellular uptake of extracellular fine particles. In this research project, we develop novel sensing systems of the intracellular environment to elucidate the mechanism of cellular uptake and the intracellular fate of extracellular fine particles. The sensing system constructed by using DNA nanostructures would allow simultaneous and real-time monitoring of multiple environmental factors during the macropinocytosis.

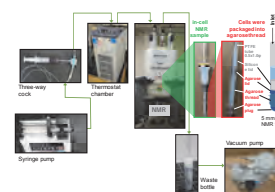


## Measures against AIDs, Japan Agency for Medical Research and Development (AMED)

Research project: On the basis of understanding of the particle formation of HIV with Gag protein from a structural viewpoint, the measures against AIDs will be developed. Particularly, in-cell NMR method will be applied for the elucidation of structure, interaction and function of Gag in living human cells.

▶ Sub-theme Leader: Prof. Masato Katahira

▶ Project Period: FY2022 – FY2024



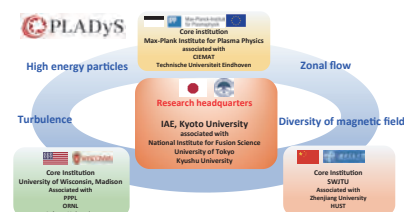
## JSPS Core-to-Core Program, A. Advanced Research Networks

### Advanced Core-to-Core Network for High-Temperature Plasma Dynamics and Structure Formation Based on Magnetic Field Diversity, "PLADyS" (JSPS)

- ▶ Leader: Prof. Kazunobu Nagasaki
- ▶ Project Period: FY2019 – FY2023

This project is aimed at constructing an international research center that creates a new science for understanding the structure formation in nature. The structure formation from the turbulent state and the role of high-energy particle dynamics in high-temperature plas-

mas confined by various magnetic fields are investigated by precise experiments, theoretical analysis and simulation. The goal is to establish an international research consortium on high-temperature plasma dynamics and structure formation in Kyoto University in collaboration with Max-Planck Institute for Plasma Physics (Germany), The University of Wisconsin-Madison (USA), and Southwest Jiaotong University (China).



## e-ASIA Joint Research Program Japan Science and Technology Agency (JST)

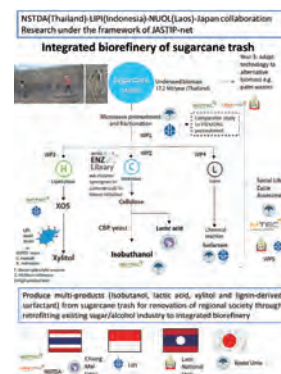
### Research area: "Alternative Energy" on the topic of "Bioenergy"

#### Research project: Integrated Biorefinery of Sugarcane Trash

- ▶ Project Leader: Prof. Takashi Watanabe (Research Institute for Sustainable Humanosphere)
- ▶ Responsible Researcher: Hideaki Ohgaki
- ▶ Project Period: FY2019 – FY2021 (extended to 2022)

[http://www.the-easia.org/jrp/pdf/1\\_Bioenergy\\_7th.pdf](http://www.the-easia.org/jrp/pdf/1_Bioenergy_7th.pdf)

This cooperative project aims to study an integrated biorefinery model for efficient utilization of sugarcane trash for conversion to advanced biofuels and biochemical using bio- and chemical processing. Social LCA will be studied to show a social impact of the proposed model.



Project scheme of "Integrated Biorefinery of Sugarcane Trash"

## Quantum-Leap Program (Q-LEAP) Japan Science and Technology Agency (JST)

### Research area: Next Generation Laser

#### Research Title: Development of Basic Technology for High Repetition Rate Attosecond Light Source Driven by MIR-Free Electron Laser

- ▶ Project Leader: Ryoichi Hajima (National Institutes for Quantum and Radiological Science and Technology)
- ▶ Responsible Researcher: Hideaki Ohgaki
- ▶ Period: FY2018 – FY2027

A free electron laser (FEL), which is generated from a relativistic electron beam, has wide tunable wavelength in Mid-infrared (MIR) with a high average power and high repetition rate. Therefore, MIR-FEL driven by a superconducting accelerator is suitable for a high-order harmonic generation (HHG) of 1 keV or more with high repetition of MHz.

The HHG driven by MIR-FEL can be an alternative technology to the HHG generated by an existing solid-state laser. In this project, key technologies to realize the high repetition rate (>10 MHz) and high photon energy (>1 keV) HHG based attosecond laser will be developed by using an existing MIR-FEL facility in Institute of Advanced Energy.



Schematic drawing of MIR-FEL based attosecond HHG laser

## Center for the Promotion of Interdisciplinary Education and Research, Kyoto University

### Research Unit for Smart Energy Management

- ▶ Leader: Prof. Yasuo Okabe (Academic Center for Computing and Media Studies)
- ▶ Leader in IAE: Prof. Toshiyuki Nohira
- ▶ Project Period: FY2016 – FY2025



This research unit aims to enhance the interdisciplinary R&D on Smart Energy Management by developing and deepening the various results obtained in Graduate School of Engineering, Graduate School of Energy Science, Institute of Advanced Energy, Graduate School of Economics, Graduate School of Informatics, and Academic Center for Computing and Media Studies, Kyoto University. The unit especially focuses on the fusion of current communication network technology and information processing technology. The unit will also conduct cooperation research projects with industry, government, schools.

### Research Unit for Non-linear/Non-equilibrium Plasma Science Research

- ▶ Leader: Prof. Hitoshi Tanaka (Professor, Graduate School of Energy Science)
- ▶ Leader in IAE: Prof. Kazunobu Nagasaki
- ▶ Project Period: FY2020 – FY2025

Kyoto University has a long history and achievement of diverse plasma research. In this unit, targeting on various phenomena dominated by non-linear and non-equilibrium nature on a wide range of spatio-temporal scales in fusion plasma, light-quanta plasma, basic / applied plasma, cosmic / astro-physical plasma, we develop research activities to build the academic foundation of plasma as a complex system full of complexity and diversity, and to explore applied researches, by sharing a wide range of knowledges and findings through active collaboration and cooperation with researches in different field, such as material science, life and biological science, mathematical science and information / computational science, etc., in which similar processes play an essential role in the phenomena of concern. Through such activities, we explore the new research approach and methodology for realizing high-performance and high-functionality plasmas carrying the next generation and contribute to develop human resources who will lead them.

### UNESCO Chair on Water, Energy and Disaster Management

- ▶ Leader: Prof. Kaoru Takara (Graduate School of Advanced Integrated Studies in Human Survivability)
- ▶ Leader in IAE: Prof. Hideaki Ohgaki
- ▶ Project Period: FY2018 – FY2022



This Chair WENDI aims to promote multi-disciplinary and holistic approach for research implementation, knowledge transfer and capacity building in the fields of water, energy, and disaster management and linkages to other sectors (food, forestry, biodiversity, climate change and data science). This is done by developing a comprehensive and trans-disciplinary Education for Sustainable Development (ESD) programme for graduate school level to establish 'KU-Model of ESD' and by providing unique international collaborative research using existing UNESCO-Sites including Geoparks, Biosphere Reserves and Cultural, Natural and Mixed World Heritage Sites as the application field. <http://wendi.kyoto-u.ac.jp/index.html>

## Kyoto University Research Coordination Alliance, Research Units for Exploring Future Horizons

Under the Kyoto University Research Coordination Alliance, 4 projects are ongoing as the organization "research unit", where IAE is involved in 2 projects.

### Unit of Data Science-based comprehensive area study (tentative name)

- ▶ Leader: Prof. Fumiharu Mieno (Center for Southeast Asian Studies)
- ▶ Leader in IAE: Prof. Hideaki Ohgaki
- ▶ Project Period: FY2020 – FY2024



In this program, 12 departments collaborate to establish a new domain "Data Science-based comprehensive area study" based on the fusion of interdisciplinary area studies and informatics. The study area will be the Asia-Pacific region, and the main areas of interest will be simulations, risk assessments, and evaluations of policy related to political, economic, and social design in those region. All participants share the viewpoint of the combination of informatics and quantitative evaluation, and conduct research by comparing different disciplines and issues between different countries.

### Unit for Development of Sustainable Human Society

- ▶ Leader: Prof. Takeshi Hasegawa (Institute for Chemical Research)
- ▶ Project Period: FY2020 – FY2025

The "Research Units for Exploring Future Horizons" called the 2nd phase program, and our proposal based on the former Unit for Development of Global Sustainability was granted. Now 8 departments adding the Academic Center for Computing and Media Studies plan to pursue sustainability study. Human sustainability goals (SDGs) with material energy circulation system and infrastructure, resilient social system will be developed and their deployment methodology will be studied. The 17 SDGs are short term targets and involves various conflicts among them. Our study will reveal the ultimate solution for long term survival of human.

# Research Facilities

The Institute of Advanced Energy conducts research at several buildings, including the main building on the Uji Campus.



Laboratory for Energy Nano-science (IAE, Bldg. N-1)



Laboratory for Photon and Charged Particle Research (IAE, Bldg. N-2)



Plasma Physics Laboratory (IAE, Bldg. N-3)



Uji Campus Main Bldg. (W wing)



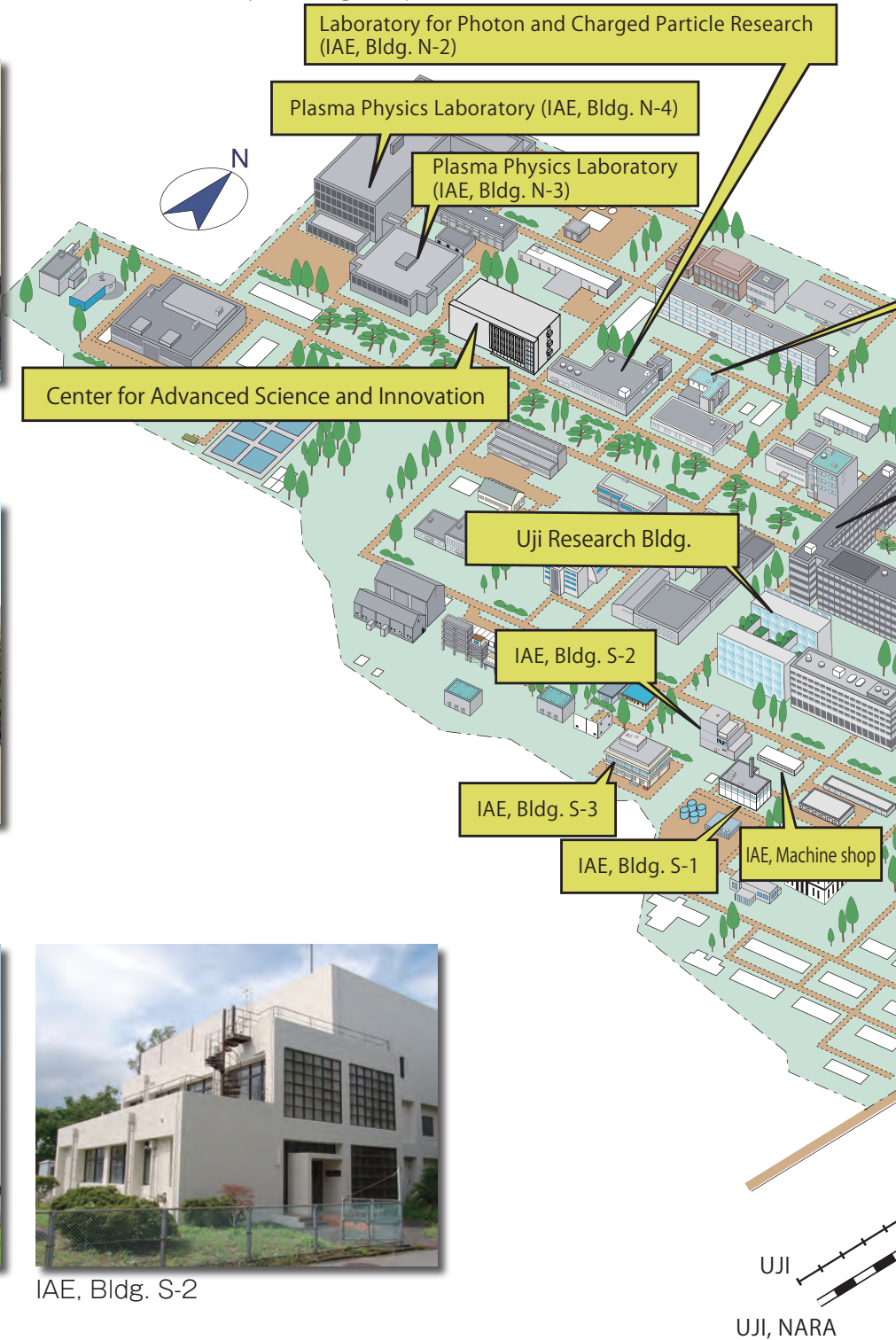
Uji Campus Main Bldg. (M wing)



IAE, Bldg. S-1



IAE, Bldg. S-2



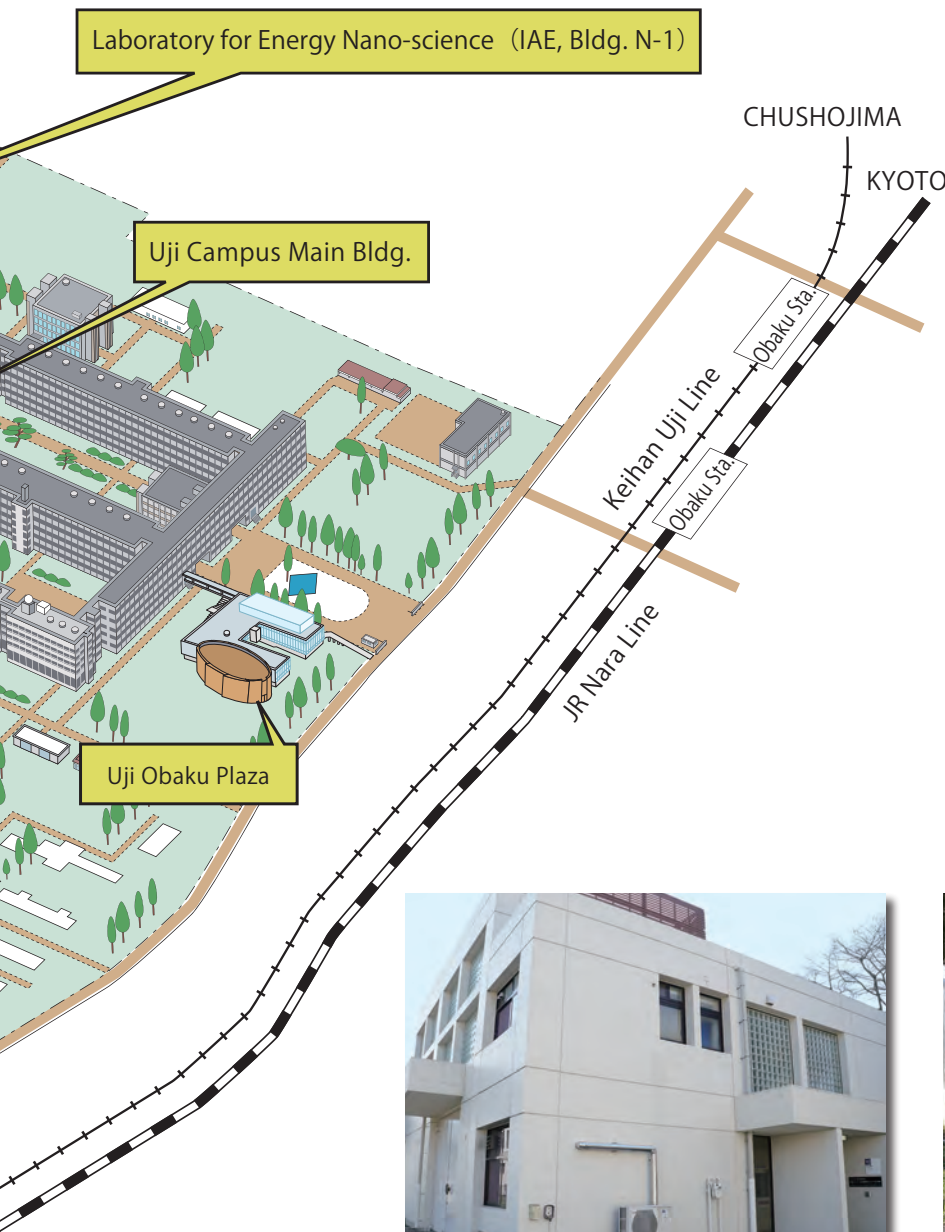




Plasma Physics Laboratory (IAE, Bldg. N-4)



Center for Advanced Science and Innovation



Uji Research Bldg.



Uji Obaku Plaza



IAE, Bldg. S-3

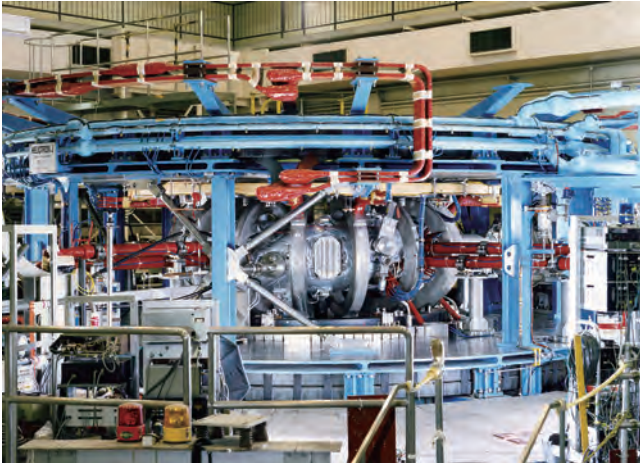


IAE, Machine shop

## Magnetic Confinement Plasma Device

Heliotron J

One of the objectives of the Heliotron J project is to explore the confinement optimization of the "helical-axis heliotron" configuration which is original to Kyoto University in its design concept, in order to develop the advanced and high-performance fusion reactor. Heliotron J started its plasma operation in 2000, and continues the improvement of performance as a unique fusion plasma experiment device.

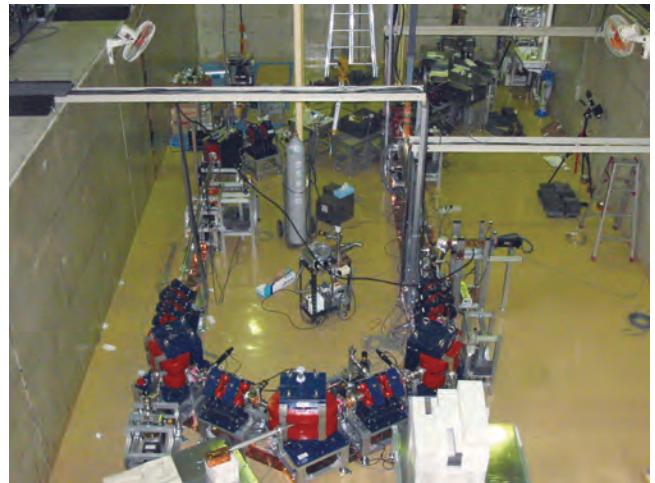


(IAE, Bldg. N-4)

## Mid-infrared Free Electron Laser Facility

KU-FEL

KU-FEL is a tunable MIR laser (3.4~26  $\mu\text{m}$ ) which is generated by a relativistic electron beam interacted with synchrotron radiation in the periodic magnetic field. Researches on energy materials by using high peak power MIR-FEL have been conducted by cooperation researchers.



(IAE, Bldg. N-2)

## Dual-Beam Facility for Energy Science and Technology

DuET

DuET is a powerful tool for introduction of lattice defects, modification of surface structure, and in-beam analysis. Two ion-beams of a different species are able to be irradiated simultaneously to the materials under various environmental conditions.

**DuET Dual-beam irradiation facility for Energy Science and Technology**  
2基のMeV級イオン加速器と高性能照射ステーションからなる施設

Temperature	4 ~ 2073K (Infrared)
Environment	Vacuum, He, O <sub>2</sub> etc.
Temperature Monitor	High resolution thermography + TC
Primary Beam (Representing ions)	6.8MeV Si 40 $\mu\text{A}$ 6.8MeV Ni 5 $\mu\text{A}$
Second Beam (Representing ions)	1MeV He 40 $\mu\text{A}$
Third Beam (Representing ions)	5keV Ar 40 $\mu\text{A}$
Particle Analysis	RBS / ERDA / OMS
In-Beam Optical Analysis	Photoluminescence, Laser Ablation
X-ray Analysis	EDS / WDS

Control Room    Singletron™    Tandemtron™ Model 31T

(IAE, Bldg. N-2)

## NMR Machines

NMR machines, an 800 MHz machine linked with liquid chromatography and mass spectrometer and two 600 MHz machines equipped with the ultra high sensitivity probe, are operated to develop the way to extract the energy and valuable materials from biomass and biomolecules.

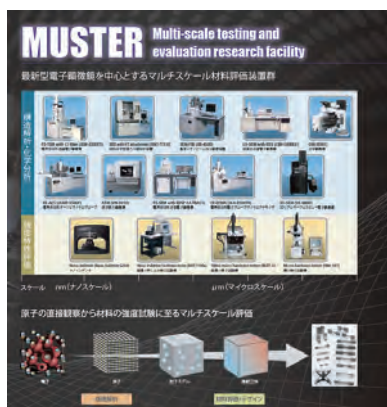


(IAE, Bldg. S-2)

## Multi-Scale Testing and Evaluation Research Facility

MUSTER

MUSTER is a research facility installed with high-resolution microscopes, TEM, FE-TEM and FE-SEM, chemical analyzers, FE-AES and FE-EPMA, and mechanical testing machines, fatigue test machine, high temperature tensile test machine and nano-indenter, etc.



(IAE, Bldg. N-1, N-2)

## Research Facilities for Energy Nanoscience

Analytical instruments for investigation of the energetic function of nanocomposites and biomaterials are provided. These involve scanning probe microscopes, atomic force microscopy, fluorescence microscope, CD spectrometer, ultraviolet and visible spectrophotometers, a fluorescence spectrometer, iso-thermal titration calorimetry, differential scanning calorimetry, MALDI-TOF mass spectrometer, ESI mass spectrometer, FT-IR spectrometer and photo-electron spectroscopy.



(IAE, Bldg. N-1, Main Bldg.)

## Functional Analytical Systems for the Generation of Catalytic Materials

Instruments are set up to purify, analyze chemical compositions and structures, and to evaluate functions of various biomolecules, organic and inorganic molecules. These include 300 MHz NMR, a protein purification chromatography system, a DNA sequencer, and a time-resolved fluorescence spectrometer.



(IAE, Bldg. N-1, Bldg. S-1, Main Bldg.)

## Fusion In-vessel Components Experiment Device

30kV-6A hydrogen beam facility and development of neutron source are ongoing for the innovative high heat flux divertor and breeding blanket for fusion in-vessel components.



(IAE, Bldg. S-3)

## Advanced Energy Conversion Experiment

For the evaluation of heat flux plasma facing components and high temperature blanket, a 950 °C LiPb liquid metal loop and compact fusion neutron source are developed. Study on interaction between material and energetic particles for the energy conversion components with advanced materials and heat transfer media will be performed.



(IAE, Bldg. S-1)

# Education and Social Activities

The Institute strives to train graduate students who are specialists with a global perspective capable of solving energy issues in the twenty-first century.

## Education

Since being simultaneously launched with the Graduate School of Energy Science, Kyoto University in 1996, each laboratory in the Institute has participated in training graduate students via a cooperative course. The steady flow of research achievements has been attracting more and more students to our Institute. Both the recent increase in the number of Ph.D. students and the higher percentage of foreign students in our student body attest to the fact we are becoming an international institute. Additionally, many of our graduate students are attracted to the Institute's unparalleled quality of advanced equipment and the diversity of our staff engaging in advanced research.

We hold briefing sessions for prospective graduate students in conjunction with Graduate School, so that potential students are familiar with issues such as our enrollment policy and selection procedure. The notable activities of our Institute include briefing sessions of our graduate school, which have been held concurrently with our open seminars, to disseminate our activities to a broad audience. These efforts have increased the student body at our Institute to 122 in FY2021, which includes 40 Ph.D. students (28 from foreign countries). We are leveraging both the Institute's Research Assistant (RA) system to increase opportunities for graduate students to network with other research institutes in Japan and abroad as well as to encourage them to present at research meetings in and out of Japan. To broaden their international perspective, many of our graduate students have participated and/or presented at international conferences. Attending international conferences plays a major role in our training activities at the Institute. We are also making efforts to expand the professional careers of our graduates, and numerous graduates have found employment at research institutes in Japan and abroad. Additionally, we jointly host public lectures with technical colleges to further our education and training activities.

We also strive to include the general public in our activities via public lectures and an open campus policy. Visi-

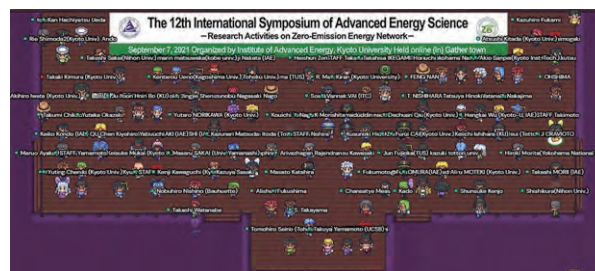
tors are always welcome. We aim to contribute to a broad spectrum of our society, including the local public activities. Additionally, the latest information is disseminated through the Institute's website, annual reports and publicity activities of the University. Since 2003, we have held annual public lectures on our campus and in the city of Kyoto to facilitate participation from the general public.

We also actively participate in Kyoto University Research Institutes' Symposium to impart our achievements. Moreover, efforts have been made to develop innovative and creative initiatives of the advanced energy fields and training activities in the nuclear power field. We are dedicated to disseminating and practically applying intellectual properties through activities such as i) collaborating with industry, government, and academia, ii) holding joint symposia, iii) actively conducting collaborative research and engaging in commissioned research, iv) providing technical guidance to industry, and v) implementing systems for the effective collaboration of industry, government, and academia. Results from these initiatives will be used in a broad array of fields to further our contributions in the international arena and to strengthen our international collaborative network.



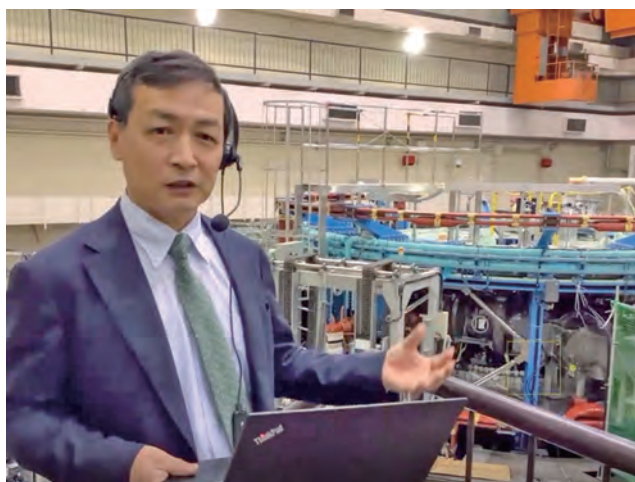
## International Symposium of Advanced Energy Science

Since 2011, the Institute has held international symposiums jointly with the Joint Usage and Research Centers to exchange the latest information with related researchers in Japan and overseas. The international symposium has consisted of plenary sessions, panel discussions, poster presentations, parallel seminars, and satellite meetings. Due to the spread of COVID-19 infection, the meeting was held online in FY2020 and FY2021.



## Public Lectures

"The 26th Public Lecture of the Institute of Advanced Energy" was scheduled at Kihada Hall of Obaku Plaza in the Uji campus, in conjunction with "Uji Open Campus 2021". This is an annual series of lectures in which selected professors of the Institute present their current research to the audiences in general public, such as office workers, undergraduate and graduate students in different fields, middle and high school students. As "Uji Open Campus 2021" was changed to be held virtually due to the spread of COVID-19 infection, the public lecture was held on line on October 17, 2021. Professor Kazunobu Nagasaki presented a lecture entitled "Maintaining plasma at one billion degrees -toward realization of nuclear fusion reactor-", together with live introduction of experimental apparatus. Then, Professor Hiroshi Sakaguchi presented a lecture entitled "Right/Left and energy". Approximately 50 audiences participated and enjoyed the event with fruitful discussion.



# International Activities

We have signed collaborative research agreements with numerous research institutes around the world to actively conduct joint research, including research visits and international conferences.

## Academic Collaboration Agreements

Date signed	Name of Institute	Country
Sep. 29, 1995	Fusion Technology Institute, University of Wisconsin-Madison	U.S.A.
Oct. 3, 1995	Fusion Studies Laboratory, University of Illinois Urbana-Champaign	U.S.A.
Oct. 6, 1995	Russian Research Centre "Kurchatov Institute"	Russia
Nov. 6, 1995	Center for Fusion Science, Southwestern Institute of Physics	China
Jun. 3, 1996	Institute of High Energy Physics, Chinese Academy of Sciences	China
Jun. 4, 1996	China Institute of Atomic Energy	China
Nov. 19, 1996	Center for Beam Physics, Lawrence Berkeley National Laboratory, University of California	U.S.A.
Nov. 20, 1996	Free Electron Laser Center, Hansen Experimental Physics Laboratory, Stanford University	U.S.A.
Dec. 12, 1996	Department of Physics, Flinders University of South Australia	Australia
Mar. 10, 1997	Institute of Material Failure, University of Science & Technology, Beijing	China
Aug. 10, 1997	Plasma Research Laboratory, Australian National University	Australia
Feb. 6, 1998	Torsatron/Stellarator Laboratory, University of Wisconsin-Madison	U.S.A.
May. 11, 1998	National Science Center 'Kharkiv Institute of Physics and Technology'	Ukraine
Aug. 1, 1998	Department of Materials Science and Chemical Engineering, Politecnico di Torino	Italy
May. 7, 1999	Industry-University Cooperation Section, Dong-eui University	Republic of Korea
July. 24, 2000	Dong-eui University (Engineering school)	Republic of Korea
Sep. 10, 2000	Korea Basic Science Institute	Republic of Korea
Jan. 9, 2001	Graduate School of Physics, University of Sydney	Australia
Jan. 25, 2001	Slovak University of Technology in Bratislava (Faculty of Electrical Engineering and Information Technology)	Slovak Republic
Jan. 5, 2001	Rajamangala University of Technology Thankyaburi	Thailand
May. 16, 2001	Spanish National Research Centre for Energy, Environment and Technology, CIEMAT	Spain
July. 24, 2001	University of Erlangen-Nuremberg (Department of Material Science, School of Engineering)	Germany
Apr. 6, 2006	National Fusion Research Institute	Republic of Korea
Nov. 28, 2006	Research Institute of Industrial Science and Technology, Pukyong National University School of Engineering	Republic of Korea
Oct. 19, 2009	Joint Graduate School of Energy and Environment	Thailand
May. 18, 2010	City University of New York, Energy Institute	U.S.A.
Apr. 12, 2012	Nano and Energy Center, Vietnam National University, Hanoi	Vietnam
Jan. 23, 2013	Fusion Plasma Transport Research Center, Korea Advanced Institute of Science and Technology	Republic of Korea
Mar. 20, 2013	Korea Atomic Energy Research Institute	Republic of Korea
Sep. 18, 2014	Center for Advanced Material & Energy Sciences, University Brunei Darussalam	Brunei
Oct. 6, 2014	Horia Hulubei National Institute of Physics and Nuclear engineering	Romania
Dec. 1, 2014	Plasma Fusion Stability and Confinement Research Center, Ulsan National Institute of Science and Technology	Republic of Korea
Jan. 8, 2019	Max-Planck-Institut fuer Plasmaphysik	Germany
Feb. 15, 2019	The Institute of Fusion Science, Southwest Jiaotong University	China
Jun. 19, 2019	Faculty of Engineering, National University of Laos	Laos
Oct. 21, 2019	Center for Fusion Science, Southwestern Institute of Physics	China
Oct. 30, 2019	International Joint Research Laboratory of Magnetic Confinement Fusion and Plasma Physics (IFPP), Huazhong University of Science and Technology	China

## The number of visitors



## International Exchange Promotion: ASEAN-JAPAN

►Leader: Prof. Hideaki Ohgaki

International exchange promotion activities among ASEAN countries are started by the 21st century COE program in 2006 and the 8th International Conference on Sustainable Energy and Environment (SEE Conference) will be held in November organized by Graduate School of Energy and Environment (JGSEE) in Thailand. In Thailand, we have also been having the Eco-Energy and Materials Science and Engineering Symposium (EMSES) in almost every year in cooperation with Rajamangala University of Technology Thanyaburi since 2001. In 2021, the 15th EMSES has been planned in Chenrai, Thailand, however, it was postponed to 2022 because of the outbreak of COVID-19. These international activities among ASEAN region have been appreciated by many counterpart universities, research institutes in Asia, Japanese government and UNESCO. In this connection, we have cooperated with UNESCO COMPETENCE program from 2009 and established the renewable energy course in 2011. As the extension of this project, we have started the ODA-UNESCO Assist program on Energy for Sustainable Development in Asia (Vietnam in 2011, Laos in 2012, Cambodia in 2013, and Myanmar in 2014, <http://www.iae.kyoto-u.ac.jp/quantum/ODA-UNESCO/>). In 2017, UNESCO selected Kyoto University as "UNESCO chair" in the field of water, energy, and

disaster prevention under the collaborative activity with Graduate School of Advanced Integrated Studies in Human Survivability, WENDI (<http://wendi.kyoto-u.ac.jp/>). In 2015, the Japan ASEAN Science and Technology Innovation Platform (JASTIP) has been adopted in JST SICORP and we have been promoting the international collaboration research between Japan and ASEAN.

In education activity, based on the MOU between Kyoto University and AUN which was initiated IAE activities, the AUN - KU Student Mobility Program towards Human Security Development (HSD) has been selected to accelerate internationalization of university in 2012. So far many sending/invitation programs, collaboration researches have been promoted under the support of JST, JSPS, Kyoto University.



Group photo of EMSES2018 in Uji Campus

and foreign students

(2021)



FY2021 was affected by the global spread of the COVID-19. visitor 10, visitor 1, foreign student+PD 10, foreign student+PD 1, Agreement

JSPS Core-to-Core Program, B. Asia-Africa Science Platforms (JSPS)

Research area: Engineering Sciences  
 Research project: Kansai-Asia Platform of Advanced Analytical Technologies

- ▶ Project Leader: Prof. Hideaki Ohgaki
- ▶ Project Period: FY2019 – FY2021 (extended to 2022)

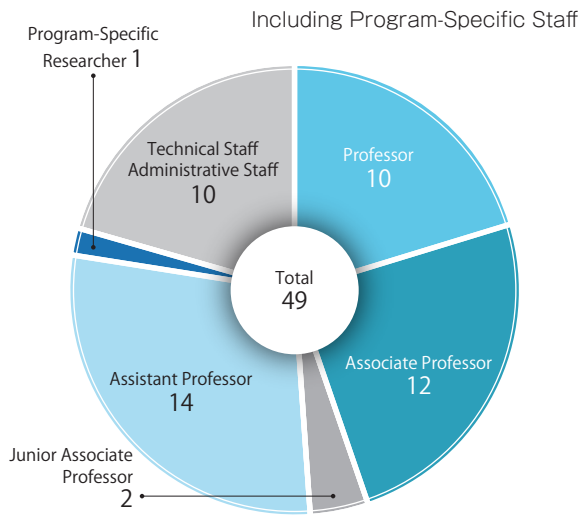
To advanced utilization of abundant natural resources in emerging Asian countries, we (Institute of Advanced Energy, Institute for Chemical Research, and The Institute of Scientific and Industrial Research, Osaka University) aim to form a research exchange platform based on our advanced analytical technologies. In this project, we will collaborate with Indonesia, Myanmar, Mongolia, Philippines, Vietnam, Cambodia and Laos to improve their analytical skills and promote collaboration research.



Program scheme of the "Kansai-Asia Platform of Advanced Analytical Technologies"

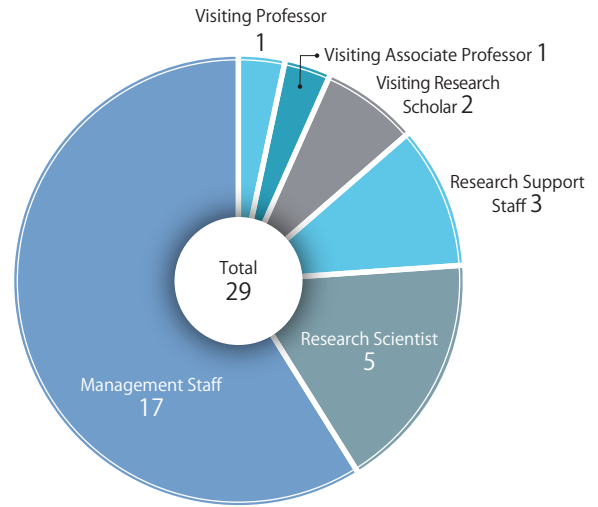
## Faculty Member

2021



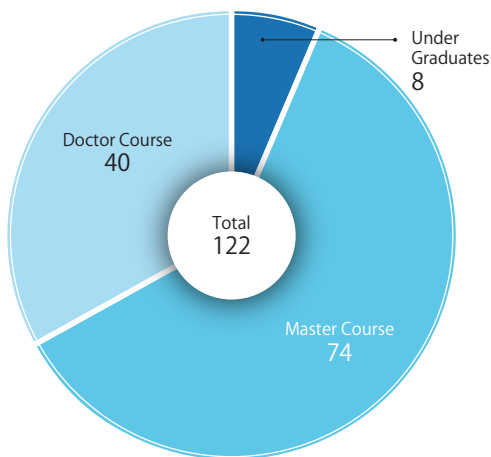
## Adjunct Member

2021



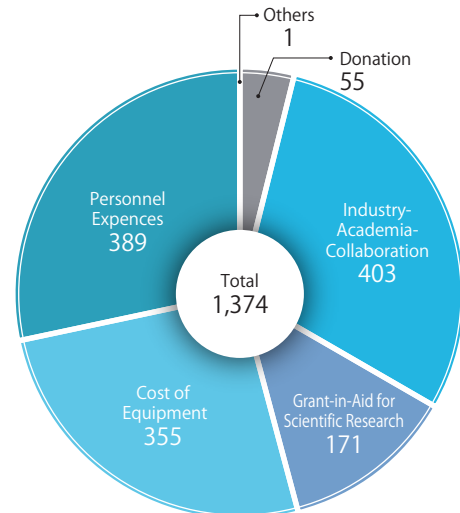
## Students

May, 2021

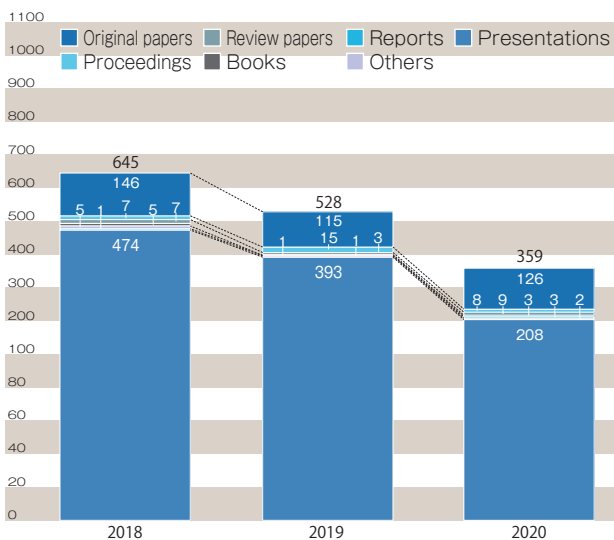


## Budget

FY2020 [unit: 1 million yen]



## Research Presentations



## The number of applicants to the collaboration program of the Laboratory for Complex Energy Processes

Category	2021
A1: Division of International and Industrial Partnership	0
A2: Division of Soft Energy Science Research	1
A3: Section of promotion for international collaborative research	4
<b>Total</b>	<b>5</b>

## The number of applicants to the collaboration program of Joint Usage/Research Center on Zero-Emission Energy

Category	2021
(A) Core research subject	43
(B) Research subject	45
(C) Facility usage	13
(D) Workshop	4
<b>Total</b>	<b>105</b>



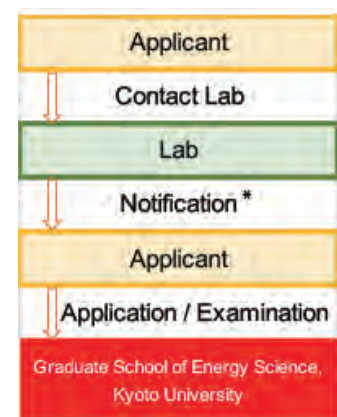
## Procedure for acceptance of graduate students at IAE

There are twelve laboratories that accept students at the IAE, we focus on research that aims towards the next generation of advanced energy among a wide range of academic fields spanning physics, chemistry, biology and engineering, as well as education that trains and produces students capable of originality and international activity. In order to study at the IAE, it is possible to either be admitted into an affiliated laboratory of the Graduate School of Energy Science, or to be enrolled as a research student. IAE is divided into different Departments. To join a lab in a given department, a student must come to an agreement with the lab supervisor. If that supervisor does not hold the title of professor, then the student must also receive additional permission from an IAE professor based on the advice of the lab supervisor. It is recommended that Applicants consult the lab supervisor prior to taking the entrance examination.

### Application process

1. Select desired lab
2. Contact supervisor and inquire about possibility of being accepted as a student. Interview, if necessary.
3. Supervisor notifies applicant of result of (2).
4. Prospective student takes Graduate School of Energy Science, Kyoto University entrance examination.

\*Master program may not require the prior agreement from the lab supervisor. Please confirm the entrance examination information of the Graduate School of Energy Science for details.



For information on application procedures and examination dates, please contact the Graduate School of Energy Science, Kyoto University.

Graduate School of Energy Science, Kyoto University

Admissions: <http://www.energy.kyoto-u.ac.jp/en/admission/>

General affairs branch

Contact Us: <http://www.energy.kyoto-u.ac.jp/en/contact-us/>

## Procedure for acceptance of research students at IAE

Apart from enrolling as a graduate student, it is possible to participate in research activities by enrolling as a research student at the IAE. If you wish to become a research student, please contact your prospective supervisor under whom you want to study and obtain a consent of acceptance. After the appointed proceedings have been completed, you will become a research student. Please note that degrees are not given to research students. For more details, please contact your prospective supervisor.

### [Contact Information]

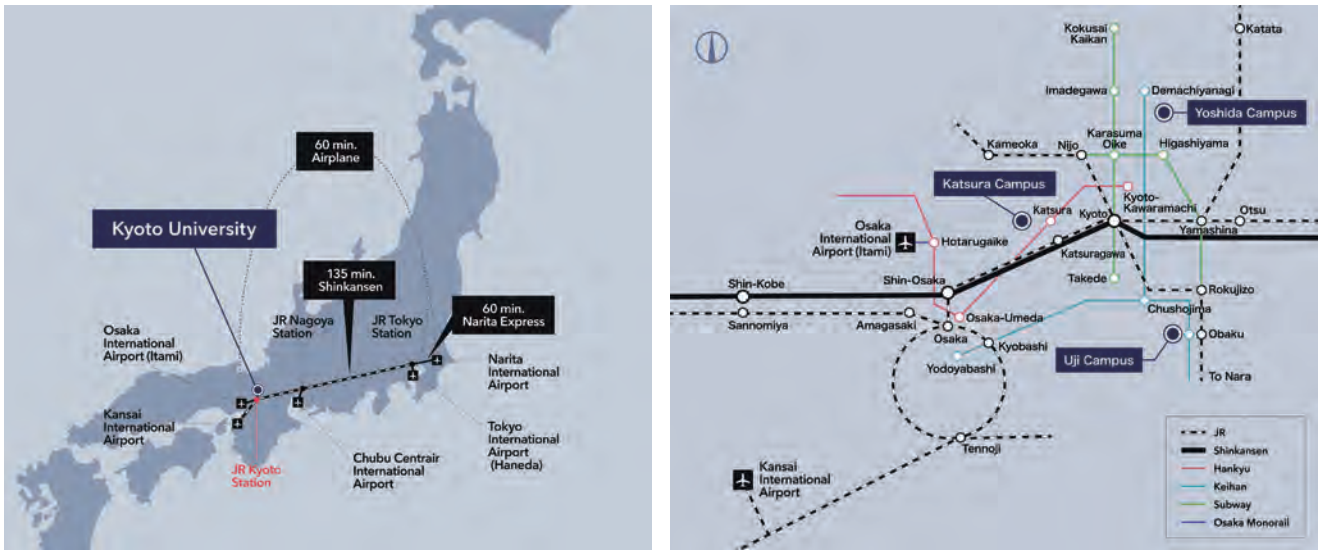
Institute of Advanced Energy, Kyoto University

Contact Us : <http://www.iae.kyoto-u.ac.jp/new-iae/en/contact/index.html>

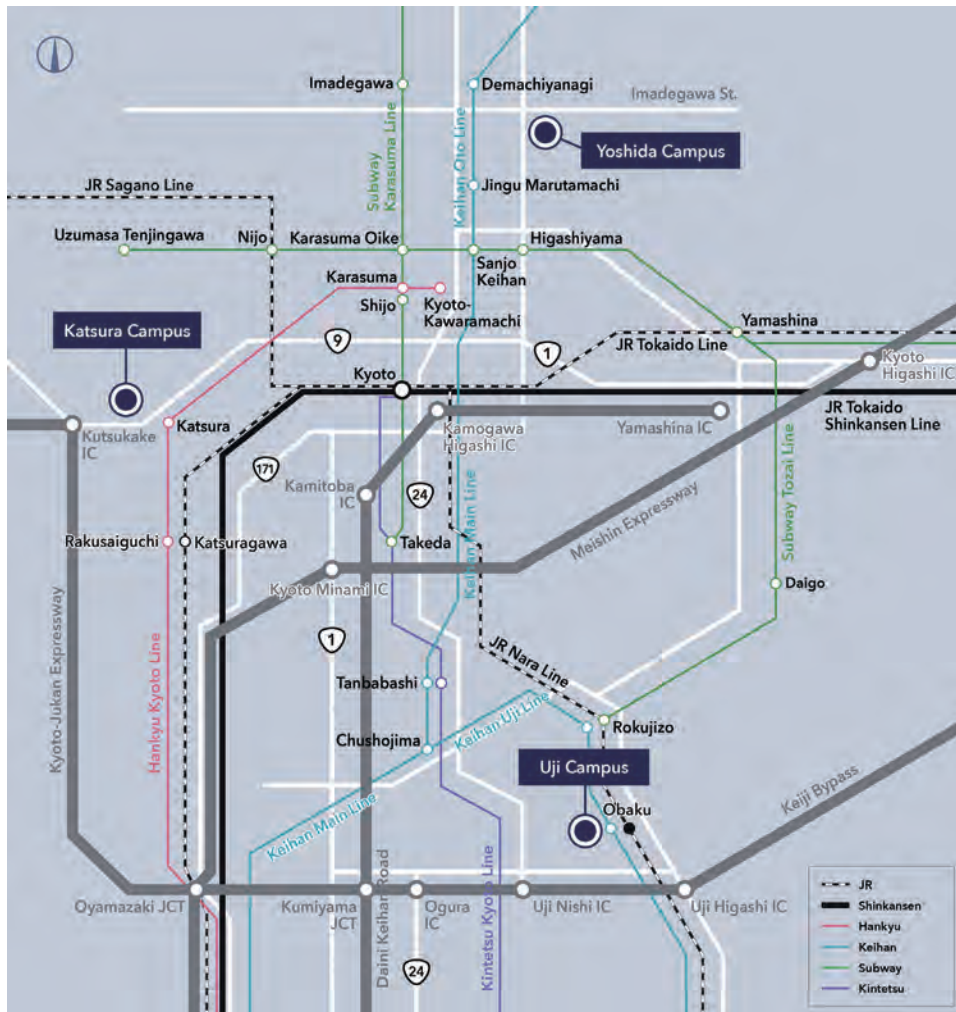
# Access to Kyoto University

Kyoto University is located in the historic city of Kyoto, which flourished as the nation's capital for over a thousand years until that status was transferred to Tokyo.

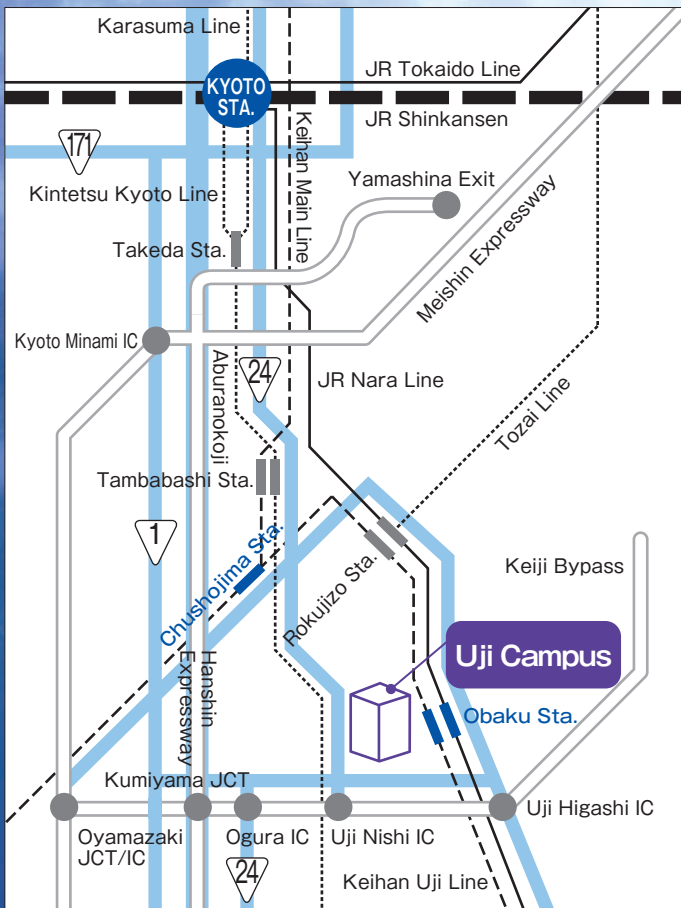
## Location in Japan



## Location of three campuses in Kyoto

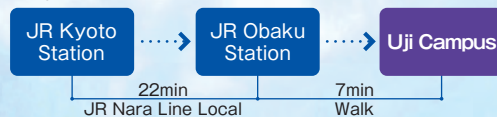




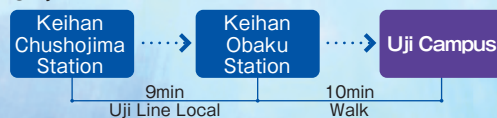


▶ ACCESS

① By JR Line



② By Keihan Line



▶ INFORMATION



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