Research Center Project

Host Institution Name	Kyushu University
Head of Host Institution	Setsuo Arikawa (President, Kyushu University)
Title of Center Project	International Institute for Carbon-Neutral Energy Research: The Grand Highway for a Carbon-Neutral Energy Fueled World
Center Project	International Institute for Carbon-Neutral Energy Research
Project Summary	<CENTER PROJECT> ○ For green energy innovations, alternate fuels to petroleum-based energy sources are required to provide reliable and sustainable energy sources for future generations. The alternate energy carriers must be produced and consumed without leaving an imprint on the environment. One such potential energy carrier is hydrogen gas; however, the transition to a hydrogen-based economy faces many challenges in terms of production, storage, delivery to end-user stations, and energy generation. A grand challenge amongst the many in this transition is the management of the CO_2 accompanying hydrogen production from promising technologies such as natural gas or carbon reformation. In order to realize a complete carbon-neutral energy fueled society based on a hydrogen economy, major advances in technologies of CO_2 capture and sequestration (CCS) are required. An international effort centered at Kyushu University will be mounted to overcome the challenges. The research effort will be focused on the fundamental science underlying development of technologies for CO_2 capture and sequestration and the realization of the hydrogen economy. In particular, the Kyushu effort will focus on the problems associated with carbon-free hydrogen production, development of hydrogen storage materials, hydrogen embrittlement resistant materials, fuel cells, material transformation, CO_2 separation and concentration, and geological storage and ocean sequestration of CO_2. Understanding the fundamentals of these problems will enable the development of solutions against global warming through a carbon-neutral hydrogen economy. ○ If one considers the future international energy landscape, there is no more opportune time for such an international research project to be undertaken. The FutureGen project in the U.S. for electricity and hydrogen production through efficient coal burning and CCS and the ongoing industrial efforts on CCS and photoelectrochemical hydrogen production, funded by the U.S. Department of Energy, are key science and technology strategies for energy independence and sustainability. The fundamental science objectives of the Kyushu Research Institute will address similar technological challenges and will serve as a platform for coordinated research between Japanese and U.S. institutions. We aspire to establish a “Carbon-Neutral Energy Research Institute” as a center of excellence in which top-level researchers collaborate, cooperate, share knowledge and exchange ideas, and discuss and debate the science issues and their impact on society. ○ From a fundamental science viewpoint, a pervading theme in all areas of the proposed research is the lack of understanding of a range of phenomena occurring at the interface between materials/rocks/ocean turbulence-eddies and gasses such as hydrogen, oxygen, and CO_2. By way of example, we do not understand i) the mechanisms by which hydrogen is adsorbed in materials making it difficult to design alloys resistant to hydrogen degradation of mechanical properties or how to design a light-weight on board storage medium with the desired hydrogenation/de-hydrogenation properties; ii) the properties and behavior of hydrogen and CO_2 under extreme pressures; iii) the triple-phase rocks/water/CO_2 interactions and the stability of geological traps; iv) the interaction of supercritical CO_2 with ocean turbulence in order to predict how ocean weather affects the efficiency of CO_2 sequestration at the bottom of the ocean. From this abbreviated list, it can readily be surmised that the phenomena to be addressed involve disparate length and time scales ranging from nanometers to thousands of

kilometers and from nanoseconds to centuries. The proposed research will address the issues as they pertain to all time and length scales, from atomic to the global scale, i.e., from the atom and molecule, to meso/macro-scale crystalline materials, to devices, up to geological formations and oceanic systems. The phenomena, although occurring at different media and disparate time and length scales, often evolve on the basis of the same processes (e.g., species adsorption, absorption, dissolution, diffusion, reaction, conduction) and are characterized by similar scientific principles. Thus, the Kyushu approach will cross-cut disciplinary boundaries through a judicious integration of information from atomistic/microscopic/macroscopic time and length scales for phenomena occurring at the interface of chemistry, physics, materials science, mechanics, geo-science, oceanic science, and biomimetics.

- The administration and management of our project will involve a constant peer evaluation and review of the research activities and outcomes in terms of efficiency and feasibility of each individual research project area as well their progress toward attaining the overall project objectives, that is, the realization of a hydrogen economy and the elimination of the CO_2 footprint. We will adopt a rigorous approach as we assess our research progress that will be predicated on how our science advances technology development and how we impact the removal of roadblocks to a carbon-neutral energy society, such as the lack of a mechanism-based understanding of fatigue of materials or the stability issues associated with supercritical CO_2 at the bottom of the oceans. Lastly, the Kyushu project will pay serious attention to the dissemination of research results and its scientific culture in the society over several fronts. Tapping into the Illinois academic expertise, we will institute societal educational outreach programs. We will leverage the expertise of the HYDROGENIUS Institute at Kyushu in organizing international development to engage the scientific communities of industry and national laboratories through specialized workshops. We plan to inform society at large through the development of web-based learning tools for all age levels, museum exhibits, as well as other strategies. This effort will pave the way for enriching public understanding of scientific achievements and at the same time teach our scientists needed communication skills.
- In summary, the Kyushu effort will carry out research on fundamental science issues underscoring the removal of roadblocks toward a hydrogen economy with zero carbon emissions through carbon capture and sequestration.

<u><RESEARCH ORGANIZATION></u>

The research effort will be organized around high profile research teams of University of Kyushu faculty. The Institute will also rely on top-level domestically and internationally recognized researchers in the fields of chemistry, physics, materials science, mechanics, geo-science, oceanic science, and biomimetics. An important component of the organization will be the Satellite Institute at the University of Illinois which will promulgate and administer research activities in the U.S.

<u><PROJECT MANAGEMENT></u>

One of the main goals of the Institute is the restructuring of research management at the Kyushu University. This new approach to research administration will rely heavily on the management style, academic experience, and scientific achievements of the Institute director whose duties will include the research team formation, the recruitment of the international research participants, the establishment of international collaborations and interactions with top research Institutions, the administration of the peer evaluation process of the Institute's research output, potential team reorganization and redirection of efforts in response to the feedback from the annual review of the Institute, review of the research personnel, and the observance of research expenditures.

The Institute is established as an organization directly under the president of the Kyushu University. The structure of the organization is such that the Institute Director

has the authority to make decisions regarding the planning and operation of the research activities, the formation and composition of the research clusters, and the budget implementation related to the management of the Institute. On all these matters, the Director is assisted by the Steering Committee (headed by the Director) and its members will be program area leaders of the Institute although the Director may invite additional members as deemed appropriate.

A vital component of the Institute is the External Advisory Committee composed of national and international leaders in the field. This committee will be convened annually or, if deemed necessary by the Director, more frequently at Kyushu University. The committee will review all aspects of the Institute, including leadership and management, research progress being made in each activity, and plans for any initiatives. The committee will provide the Director with a written report on their findings and recommendations. The final decision regarding Institute activities and directions will be the responsibility of the Director.

The Director is assisted by the Associate Director for the management of the Institute's research activities. The Office of the Director is supported by the Administrative Director, head of the Institute's Administrative Office, whose purpose is to provide administrative support to the research personnel of the Institute. The official language of the Institute's Administrative Office is English. To ensure efficiency and expediency of operations in the Administrative Office, we will opt for post-doctoral researcher employees so that carrying out of the operations is done by personnel that understand the research activities of the Institute.

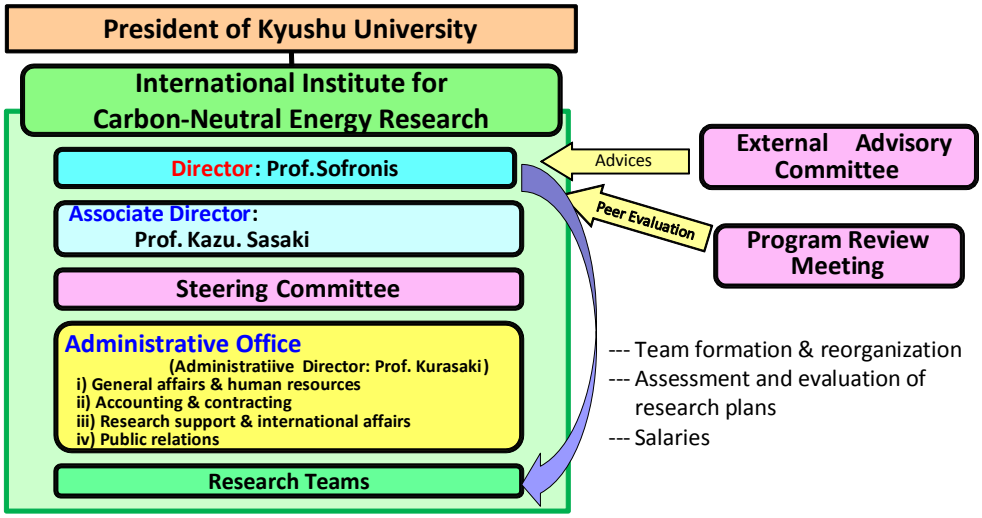

Fig. Administrative structure of the Institute

<COLLABORATIONS WITH OTHER INSTITUTIONS>

○ To carry out its mission, the Institute will seek to establish collaborations with internationally recognized research centers, universities, as well as national and international laboratories. These collaborations will involve and promote research interactions and researcher exchanges and visits between institutions. The framework will be in the form of a Satellite Institute in the case of the University of Illinois and collaborating institutions for the all other cases.

a) Satellite Institute (University of Illinois at Urbana-Champaign, USA)

- The Director of the WPI Institute, Professor P. Sofronis, is a faculty member at the University of Illinois at Urbana-Champaign, Illinois, and is an internationally recognized expert on the effects of hydrogen on the mechanical properties of materials. Other research activities at Illinois mirror parts of the proposed program, therefore, a satellite office will be established at Illinois to facilitate cooperative research activities as well as personnel exchanges. In addition to conducting Institute-related research, the Satellite will serve as the base for identifying and engaging key research programs and faculty at national and international

universities and institutions. As Director of the WPI Institute, Professor Sofronis will also serve as Director of the Satellite Institute. In this latter capacity he will report directly to the Dean of the College of Engineering at the University of Illinois. Appropriate agreements between Kyushu University and the University of Illinois, other than an exchange of students which is already in place, will be negotiated if the Institute is funded. Both parties have expressed interest and support for establishing this satellite institute at the University of Illinois.

b) Collaborating Institutions

- We plan to engage in collaborative research with distinguished scientists from internationally recognized institutions. This includes site visits to facilitate research by leveraging research capabilities.

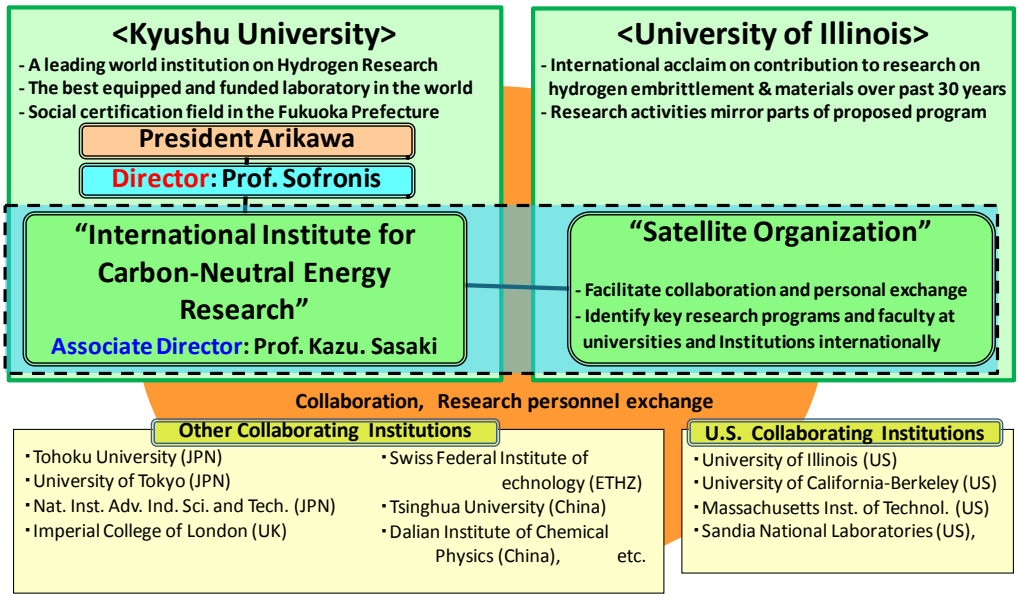

Fig. Collaborations with other institutions

(1) Research Field

Research field:
Fundamental science for an economy based on carbon neutral energy.
(Multi/inter-disciplinary Science integrating Chemistry, Physics, Materials Science, Mechanics, Geoscience, Oceanic Science, and Biomimetics)

Significance of the proposed project:

- ○ There is a vital need to develop sustainable sources of energy without CO_2 emissions, and to establish safe and reliable carbon capture and storage (CCS) systems for the realization of a carbon-neutral energy society.
- ○ From the viewpoint of limited fossil fuel resources, energy security, capital outflow, and economic instability due to increasing oil prices, there is an urgent need to establish a flexible energy system which integrates a diverse range of energy sources with no dependence on fossil fuels.
- ○ In particular, due to the unique properties of hydrogen energy described below, there are increasing expectations for hydrogen fuel to play a very important role, not only as a leading and ultimate choice for an alternative energy source for the establishment of sustainable development and a carbon-neutral energy society, but also as a promising energy carrier that can be produced from a diverse range of energy sources. The benefits of a hydrogen-fueled economy used in conjunction with CCS systems are summarized as follows:
  a) Hydrogen does not produce any CO_2 when it is utilized (burnt).
  b) Hydrogen fuel cells are significantly more efficient when compared to the ordinary/existing

energy generation systems based on the combustion of fossil fuels—the chemical energy stored in fossil fuels has to be converted to heat to obtain the useful electrical energy, a process which produces wasted heat energy, i.e., not all energy stored in fossil fuels can be utilized.

c) Hydrogen can be produced by using a diverse range of technologies such as electrolysis, nuclear heat utilization, reforming of fossil fuels, and/or photocatalytic water splitting. Especially, the energy in natural recourses, which is stored at low densities, can be converted to a concentrated chemical form in hydrogen energy systems.

d) Hydrogen energy (i.e., chemical energy) can be efficiently converted to electrical energy, and vice versa, by using technologies such as electrolysis and fuel cells.

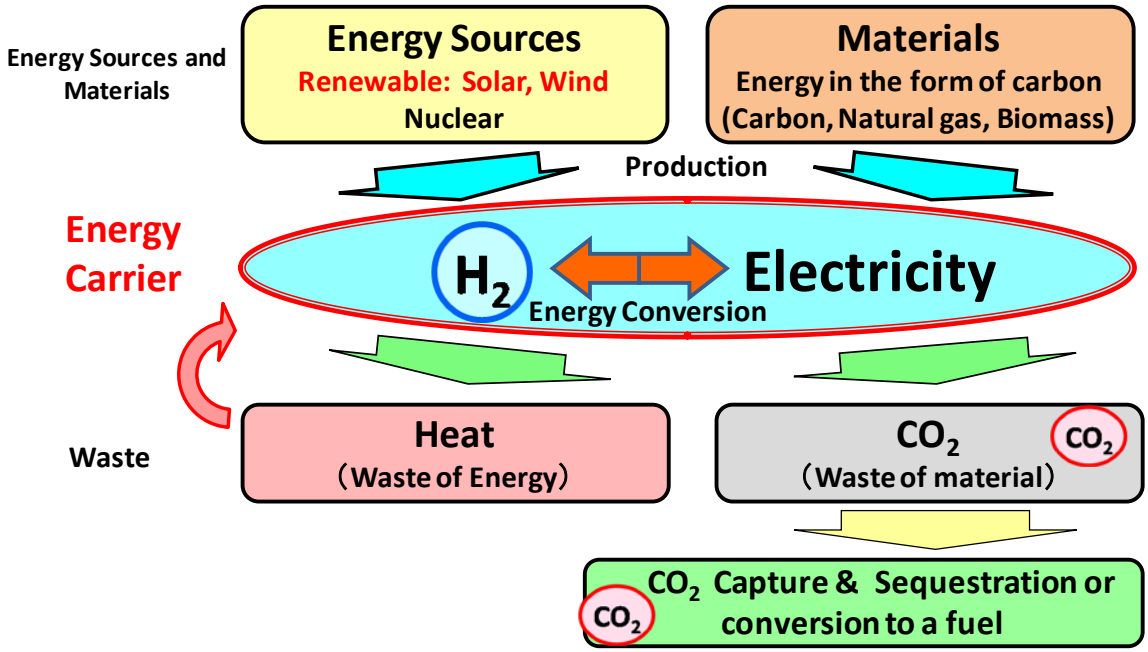

Fig. A Carbon-Neutral Energy Fueled System

The production of hydrogen and the CCS process require energy inputs. It will defeat the purpose of a clean/sustainable energy system, if the energy input (e.g., the energy generated from fossil fuels) exceeds the chemical energy extracted from hydrogen, or if the CO_2 emission from the energy utilized in a CCS process exceeds the actual CO_2 captured and stored. Moreover, as stated above, carbon-based energy sources (e.g., fossil fuels and biomass) require a combustion process to produce useful electrical energy and heat. This process produces waste heat energy and emits CO_2 byproducts. Electrical energy and heat energy are also generated from renewable energy sources, such as solar, wind, and geothermal energy. The final byproduct of these processes is also waste heat energy due to the inefficiencies in the conversion process. Therefore, it is vital that we develop an optimum/economical holistic energy system which minimizes overall CO_2 emission and waste heat energy, with flexible but appropriate combinations of the following technologies:

a) Highly efficient production of hydrogen from existing energy production systems (thermal electric power generation and nuclear power generation systems) with both fossil fuels and renewable energy sources, in combination with reuse of waste heat energy within the systems.

b) Highly efficient energy conversion between hydrogen (chemical) energy and electrical energy.

c) Highly efficient carbon capture and storage.

Thus, it is important to approach the research issues underlying the development of hydrogen energy and carbon capture and storage from a holistic viewpoint and a careful examination of the interdependencies between the components and stages of the entire energy system.

Japan has been one of the world's pioneers in the field of renewable/clean energy technologies such as fuel cells for residential application, fuel cell vehicles, and hydrogen stations, and we, especially the Kyushu University, have a strong research record and cutting-edge research facilities in these fields. For example, Kyushu University is internationally recognized for its research activities related to hydrogen energy from fundamental science issues to the assessment and evaluation of actual fuel cells and hydrogen stations. Thus, the existing research foundations and

accomplishments of Kyushu University provide a valuable and advantageous setting for launching the proposed international effort. Although the research on carbon capture and storage has been intensively undertaken worldwide, there are still a number of critical issues to be addressed in terms of the long-term safety and reliability of CCS systems. Thus, it is crucial to strengthen the scientific foundation underpinning these technologies for its practical application. In the area of fundamental research for geological storage, the Kyushu University has ongoing research activities on the effect of SO_x on the CO_2 storage capacity and the physicochemical behavior of CO_2 in shallow ocean beds. In addition, in the area of ocean sequestration, Kyushu University is currently pursuing the development of ocean circulation models and virtual moorings systems for monitoring.

- To remove the roadblocks to the realization of a carbon-neutral hydrogen economy, the proposed research will focus on: hydrogen production; hydrogen storage materials; hydrogen-induced material degradation; fuel cells; material conversion; carbon capture; ocean sequestration; and geological storage. To achieve the breakthroughs needed to develop the required technologies, it is essential to understand the fundamental processes and reactions occurring at the interface between materials and hydrogen, oxygen or CO_2. This project will undertake research across multiple temporal and spatial scales on phenomena characterized by a commonality of challenges, e.g., issues of absorption, adsorption, dissolution, diffusion, reaction, and conduction. Therefore, solving the current energy and environmental problems will necessitate the integration of atomistic to macroscopic approaches.

- To achieve these research goals, it is essential for scientists and engineers from various research fields, such as chemistry, physics, materials science, mechanics, geoscience, oceanic science, and biomimetics to conduct research together on the same topics. The synergy generated will consequently result in a positive influence on the overall research outcome, and lead to the development of innovative technologies.

(2) Research Objectives

- Our ten-year research goal is to establish innovative, safe, and reliable technologies for the production, storage, and utilization of hydrogen (hydrogen production; hydrogen storage materials; hydrogen embrittlement resistant materials; fuel cells; material conversion), as well as for CO_2 separation and concentration, CO_2 geological storage, and ocean sequestration. To attain this goal, our approach will involve multiple disciplines such as chemistry, physics, materials science, mechanics, geoscience, oceanic science, and biomimetics in order to investigate phenomena such as species diffusion taking place at the interface of interactions between materials and hydrogen, oxygen, and CO_2 at all scales, from the atomic to those for oceanic systems and from nanoseconds to decades. We also aspire to contribute to the societal debate by informing and educating the public on ocean sequestration and geological storage through sound scientific data and on the benefits of transitioning to a carbon-neutral energy society. In the following, an outline of our individual research objectives is presented followed by a detailed description of the related research methodologies:
  - Development of high efficiency material conversion processes without any by-products such as waste and CO_2.
  - Development of innovative and sustainable hydrogen production processes, such as photocatalytic water splitting;
  - Development of novel hydrogen storage materials with storage capacity of over 6wt% H_2;
  - Design of hydrogen-embrittlement resistant materials for the development of a safe and reliable material infrastructure;
  - Development of next generation fuel cells by the research on novel materials and devices;
  - Development of low-energy carbon separation and concentration processes;
  - Development of CO_2 geological and ocean sequestration by understanding CO_2 behavior;
  - Increase public awareness for hydrogen technologies and long-term CO_2 behavior in each earth and ocean;

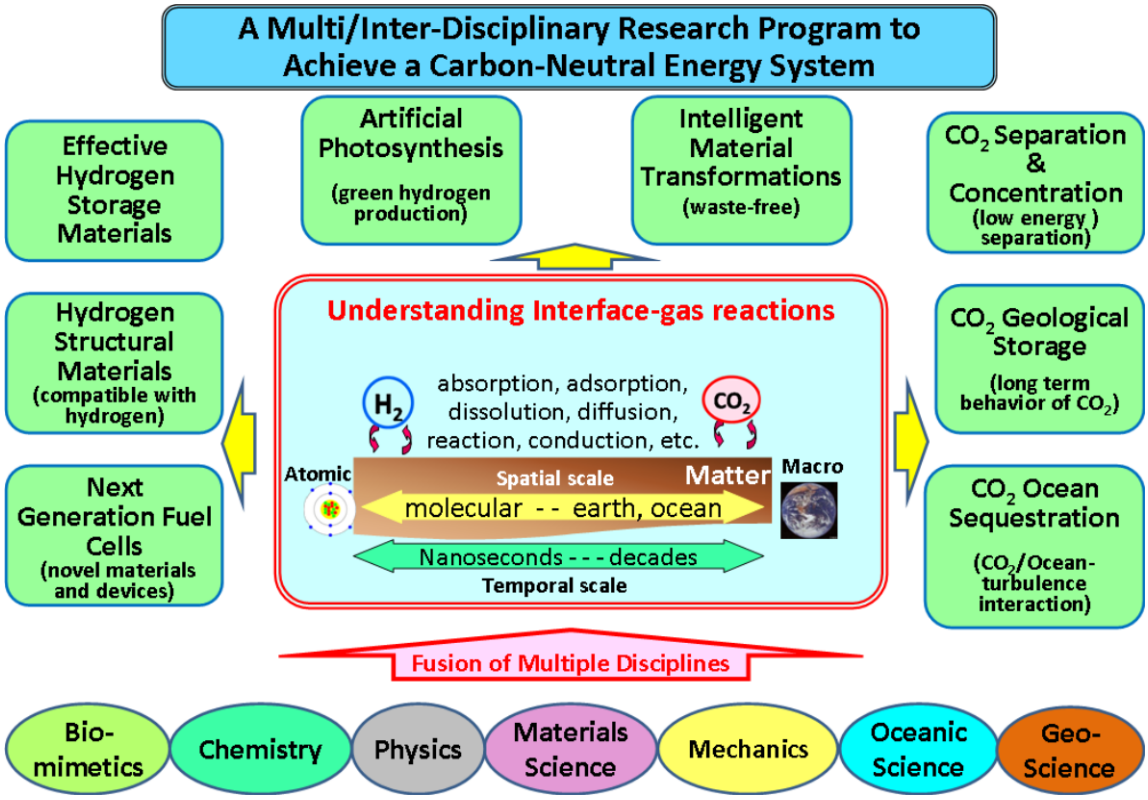

Fig. Interfaces in this multi/inter-disciplinary research program in the Carbon-Neutral Energy Research Institute

<EXAMPLE OF RESEARCH OBJECTIVES AND METHODOLOGY>

1) Artificial photosynthesis through complete photocatalytic water splitting by the Z-scheme type excitation mechanism

- Artificial photosynthesis, specifically photocatalytic water splitting**,** is a promising approach for innovative hydrogen production without CO_2 generation; however, currently, complete water splitting has not been achieved.
- We will investigate the generation of hydrogen through complete photocatalytic water splitting and apply these principles to i) innovative solar cells development, and ii) conversion of CO_2 to functional compounds in combination with electrolytic techniques mimicking dark reactions.
- Our research will contribute to the development of a hydrogen production technology without CO_2 emission and the conversion of CO_2 to functional compounds using sunlight, through the integration of molecular chemistry, biomimetics, green chemistry, and surface chemistry.

2) Hydrogen materials compatibility: mitigation/remediation strategies against hydrogen embrittlement

- Hydrogen embrittlement is a severe environmental type of failure that can cause a sudden and catastrophic failure under normally safe working loads in almost all materials. Information regarding the wide spectrum of pathways through which hydrogen degrades material properties depends upon the in-service conditions remains insufficient.
- Assessing component lifetime, developing mitigation or remediation strategies, or designing smart structural materials for employment in a hydrogen environment are not yet feasible.
- The proposed effort seeks to fulfill this challenge by devising a program that employs synergistic experimental and computational methodologies over multiple spatial and temporal scales.

- The objective of the proposed research is to i) remediate the problem of hydrogen embrittlement in existing materials by developing mitigation strategies and possibly suppressing it altogether; ii) design materials that are not susceptible to hydrogen embrittlement over a wide range of operating conditions through employing experimental and computational methodologies.

3) Materials for the next generation fuel cells: fundamentals of high efficiency energy conversion systems and development of novel devices

- Fuel cells can efficiently convert chemical fuels, such as hydrogen, to electricity, and are the core technology in a hydrogen energy society. However, there has been no practical application of such fuel cells due to the restricted operational conditions of fuel cell materials. Therefore, a breakthrough in the development of innovative materials for fuel cells is crucial.

- In this project area, the goal is to develop innovative electrolyte materials, electrode materials, and new devices for fuel cells, based not only on established research methodologies, but by resorting to the fundamental studies of the chemistry and electrochemistry of solids at material interfaces and in nano-regions.

- In particular, we will carry out research on the development of electrolyte materials and electrode materials for the next generation of fuel cell devices. The research for these materials are based on the following fundamental investigations: (i) nano-electrochemical measurements of parameters such as electrical, electrochemical and catalytic properties of nanostructures materials with strong meta-support interactions; (ii) computational science to calculate microscopic processes such as surface adsorption and diffusion, and macroscopic processes such as ionic and electronic conduction, mass and heat transport; and (iii) molecular chemistry, surface science, and materials research to understand surface and interfacial transport phenomena in model surfaces and interfaces.

4) Thermal and flow properties of hydrogen and CO_2 under extreme pressures

- Development of hydrogen and CO_2 storage technologies requires the knowledge of fundamental thermophysical properties of hydrogen and CO_2 under extreme pressure conditions, e.g. 100MPa. Properties, such as PVT-relation, specific heat capacity, thermal conductivity, and heat transfer characteristics are not available at high pressures, and values extrapolated from low pressure measurements are currently used.

- Research will be conducted on conversion rates between orthohydrogen and parahydrogen, the thermal properties and heat transfer characteristics of supercritical carbon dioxide, and the adsorption and desorption properties of carbon dioxide to develop accurate thermophysical property database for a wide range of temperatures and pressures.

5) Hydrogen storage materials: development of high-efficient hydrogen transport and storage technologies.

- The volumetric energy density of hydrogen gas is significantly small for gaseous storage to be considered as an efficient means, development of a compact, safe, inexpensive, and highly efficient hydrogen storage technology is required; currently, so far the highest worldwide hydrogen storage capacity of 3wt% H_2 has been achieved. However, we maintain that improvement in mass energy density of hydrogen storage is still possible.

- By applying a diverse range of approaches to molecular chemistry, surface science, solid mechanics, solid-state physics, and materials science, we will investigate i) the bond property between hydrogen and storage materials for the control of reaction temperatures; ii) the position of hydrogen in the storage materials that is potentially associated with the highest hydrogen storage capacity; iii) the new structures by various methods such as extreme pressure method; and iv) the transport properties of hydrogen, we aim at developing materials with the storage capacity of over 6wt% H_2.

6) Asymmetric oxidation for material transformation : toward discovery of a catalyst process for a "zero-waste/no-carbon" reaction

- A large number of functional material substances used in everyday life are derived by chemical transformations from fossil fuels. These chemical reactions require substantial energy expenditures and usually result in the creation of huge amounts of waste as well as the emission of unwanted CO_2. Therefore, development of new and efficient approaches to chemical reactions for material transformation will help in the direction of diminishing the society's carbon footprint and assist in energy sustainability given the limited availability of fossil fuels. We will undertake this task of "greening" chemical reactions for material conversion by focusing on the development of asymmetric oxidation through employing atom-efficient oxidants.

- By integrating various fields such as green chemistry, molecular chemistry, surface chemistry, charge-mass-thermal conversion, and biomimetics, we plan to create i) an asymmetric oxidation system without proton-electron transfer; ii) photooxidation of water and CO_2 photoreduction catalyst system; and iii) activation system of hydrogen, oxygen, water, nitrogen and CO_2, and create sustainable energy transformation system.

- Our goal is to develop new molecular catalysts and efficient material transformation methods based on oxidation and reduction.

7) Fundamentals of advanced CO_2 separation and concentration systems: toward an efficient and low cost CO_2 separation and concentration technology

- Currently, a large number of methods exist for the separation of CO_2 produced in the combustion of fossil fuels; however, none of them have found practical application due to the large amount of energy required for the separation processes.

- In this project area, we will carry out fundamental research in order to improve adsorption and absorption of CO_2 in membranes and develop a highly efficient and low-cost electrochemical CO_2 separation process.

- We propose that a CO_2 absorption process be used in conjunction with water electrolysis through ion exchange membranes, where CO_2 is absorbed by the alkaline solution produced from the process and the produced hydrogen can be captured to be utilized. Further, for the absorption and adsorption processes, we plan to investigate an optimum structure of adsorbent as a novel and unique adsorptive material which can easily desorb the absorbed CO_2.

- The research will be carried out by integrating approaches from various disciplines such as fluid mechanics, surface science, charge-mass-heat transfer theory, and electrochemistry. In addition we will collaborate with other research groups in the Institute, e.g., hydrogen production, fuel cells, and CO_2 storage groups.

8) CO_2 geological storage: understanding CO_2 behavior in underground reservoirs and the development of numerical prediction models

- CO_2 geological storage is carried out in underground reservoirs over around one thousand meters below the surface. There have been a limited number of studies on the long-term safety and reliability of CO_2 geological storage, and as a consequence issues related to the dissolution and trapping of CO_2 to water, oil, rocks and coals in highly pressurized porous layers, and CO_2 gas diffusion through faults near the ground surfaces remain poorly understood.

- Our research approach is to integrate a diverse range of disciplines such as molecular chemistry, surface science, green chemistry, solid mechanics, physics, biomimetics, and geoscience to understand dissolution, transformation, and mineralization of CO_2 at the triple phase boundary of rocks/coals, water/oil and CO_2 in micropores under high pressure. We will also investigate the microbial CH_4 conversion mechanisms. The ultimate goal is to develop a

numerical simulation tool for CO_2 diffusion, by testing and evaluating the diffusion behavior of CO_2 from the underground reservoirs to the ground surface including both saturated and unsaturated layers.

9) CO_2 Ocean sequestration: informing the public on ocean sequestration

- Ocean absorption helps to naturally remove CO_2 from the atmosphere; however, due to the ever-increasing rate of CO_2 emission into the atmosphere, we are at a stage where the rate of CO_2 emission exceeds the removal rate. In order to meet CO_2 emission reduction targets, CO_2 ocean sequestration is expected to play an important role. However, there are still many unresolved issues that need to be addressed, e.g., the stability of the ocean/CO_2 system in the presence of meso-scale eddies and the upwelling and environmental and biological impact of acidification of the oceans.

- This project area will evaluate the stability of CO_2 and the impact on the oceanic and global environments. Further we will analyze and determine the risks of CO_2 injection and monitoring systems in order to increase our understanding and inform the public on the advantages or disadvantages of ocean sequestration.

- In particular, we will investigate the behavior of CO_2 in the presence of meso-scale eddies and the upwelling and environmental and biological impact of acidification of the ocean by using the tools of fluid mechanics and oceanic science. For analysis, the ocean current model developed by Kyushu University will be used in conjunction with a carbon circulation model.

10) Carbon neutral energy fueled society

- In terms of the key technologies supporting the carbon-neutral energy society, we plan to carry out our research activities through constant evaluation of the research performance with regard to the efficiency and feasibility of each of the project areas and their potential contributions to the elimination of CO_2 emissions. We will assess the research progress of the Institute and clarify the meanings and importance of our developed technologies from the public's perspective.

(3) Management

i) Director

Name: Petros Sofronis (Age 53)
Position Title, Affiliation: Professor, University of Illinois, USA
Specialties: Solid mechanics, Finite element methods, Micromechanics of materials, Elastic-plastic fracture mechanics, Hydrogen embrittlement.

Suitability as Institute Director:

Prof. Sofronis' education and research orientation are in the area of mechanics of materials that includes the disciplines of elasticity, viscoelasticity, plasticity, fracture mechanics, and micromechanics of defect interactions.

Professor Sofronis has been active in the field of environmental degradation of materials for nearly 30 years. Since 1991, Sofronis has been a principal investigator in the interdisciplinary environment of the Materials Research Laboratory at the University of Illinois at Urbana-Champaign. Sofronis has investigated phenomena of hydrogen embrittlement of materials by coupling mechanics of materials with experimental observations at the atomistic scale. His theory on the hydrogen-induced shielding of defect interactions to explain the mechanism of hydrogen enhanced localized plasticity for embrittlement is the first proposed rational explanation of the hydrogen-induced fracture given worldwide. Recently, Sofronis is working on materials for the new hydrogen economy in collaboration. His research aims at developing and verifying a lifetime prediction methodology for failure of materials used in hydrogen gaseous environments.

Development and validation of such predictive capability and strategies to avoid material degradation is of paramount importance to the rapid assessment of the suitability of using the current natural gas pipeline distribution system for hydrogen transport in the new hydrogen economy and of the susceptibility of new alloys tailored for use in hydrogen related applications

Professor Sofronis' expertise on the interaction of materials with severe chemomechanical environments is extremely relevant to the fields that constitute the main theme of the proposed research Institute: gas interactions (H, O, and CO_2) with matter. Therefore, it is expected that his internationally recognized scientific credentials will enable him to administer the Institute's research activities by applying and requiring the highest standards for high quality research.

The research objectives of the Institute cover a broad range of research areas and this requires expertise that cross-cuts discipline boundaries. The overarching goal is to establish the fundamental science underlying the technology of innovative, safe, and reliable systems for the production, storage and utilization of hydrogen (hydrogen production; hydrogen storage materials; hydrogen embrittlement resistant materials; fuel cells; material conversion), as well as for separation of CO_2, carbon oceanic and geological sequestration and conversion to more usable forms. To reach this goal requires establishing a fundamental-science understanding at the atomic level of such phenomena as adsorption, absorption, dissolution, diffusion, reaction characterizing interaction of gases and matter in the framework of two-phase fluid and solid systems. By publically disseminating research findings we expect and aspire to contribute to the societal discourse on the scientific soundness of ocean sequestration and geo-sequestration.

The research organization of the Institute will be theme based. Four broad-based divisions are envisioned initially: Hydrogen Production and Delivery; Hydrogen Storage; CO_2 capture, sequestration and conversion; and energy and society. Each will be lead by a science advisor who will be responsible for setting the scientific objectives and goals and for the day-to-day management. In addition, each division will be staffed by outstanding research faculty and staff who will be drawn from Kyushu University as well as other national and international universities and national laboratories. To drive the research mission and to ensure each program area/division has the needed expertise, the Director along with the Principal Investigators will invite periodically scientists and engineers from around the world to submit a white paper addressing how they could contribute to critical mission issues. The Director may seek input from the members of the External Advisory Committee as to the merits and value of these white papers to the overall mission of the Institute. This approach will ensure that the research environment remains dynamic and staffed with scientists and engineers that have the needed expertise.

Professor Sofronis has a large number of ongoing synergistic research activities and collaborations with researchers from the US Academia (e.g., Berkeley, Penn), national laboratories (e.g., Sandia, Los Alamos), and Industry (e.g., ExxonMobil). This research network experience is a demonstrable example of how capable he is on carrying out and administering collaborative research efforts.

ii) Administrative Director

Name:Takaaki Kurasaki（Age 48）
Position Title, Affiliation: Professor, Office for Strategic Research Planning, and Vice Director, International Research Center for Hydrogen Energy, Kyushu University

Prof. Kurasaki has worked on the design and promotion of R&D projects at the Ministry of Education, Culture, Sports, Science and Technology of Japan. At Kyushu University, he has been directing and supporting external research grant applications and assisting in the development of research supporting operations. Recently, he was involved in the development of a research support system for a professor of the Kyushu University who had won the research grant, "Funding Program for World-Leading Innovative R&D on Science and Technology." Prof. Kurasaki also serves as Vice Director of the International Research Center for Hydrogen Energy in Kyushu University and is extremely knowledgeable of the entire hydrogen research enterprise at Kyushu University. He has been coordinating the development of this WPI grant application from its nascent stage, and managing the communications with the Institute Director, Prof. Sofronis. According to Prof. Sofronis, Prof. Kurasaki is a very competent and efficient administration manager equipped with the requisite social skills.

iii) Composition of Administrative Staff

- In order to efficiently respond to the requests from the Institute Director and researchers, and also to provide an ideal research environment, there will be an Administrative Office specially set up for this Institute. The office will consist of 1) general affairs and human recourses section; 2) accounting and contracting group; 3) research support and international affairs; and 4) public relations.
- The administrative officers in the Administrative Office of the Institute will get support from other administrative officers in the Kyushu University who have competent English language skills. Personnel outside the Kyushu University with competent technical knowledge, experience, and English language skills will also be employed in the Administrative Office. The official language in the Administrative Office will be English.
- Further, it is vital that personnel in the Administrative Office have some technical knowledge in its support role for the international activities of the Institute, such as the preparation of grant application documents, presentation of research findings, project designs and agreement for collaborative research work, and application for and management of patents. For such an efficient and competent research support system, we are to appoint postdoctoral fellows as Research Administrators (RAs). These fellows will help in the formation of a research environment such that researchers in the Institute will be able to concentrate on their research activities. This will also help establish the RA concept, which is fairly uncommon in Japan, as a new attractive career path for postdoctoral fellows.
- The Institute will offer support to international researchers for their research activities as well as other services both within and outside the University, in close cooperation with the existing International Student and Researcher Support Center of the Kyushu University. The Institute will offer full-time support including visa applications, accommodations, airport pickups, administrative procedures at the University, alien registrations, paper work and processes required for banking, school attendance, etc., and the purchasing of essential items such as mobile phones, and related payments.

Below are the main tasks allocated to each of the departments:

1) General Affairs and Human Resources
   General management of the Institute, preparation of meetings, management of Institute policy, human resource management such as employment, salary and business trips, safety management, and support services for international researchers
2) Accounting and Contracting
   Compiling of budget, resourcing of Institute facilities, equipment and other goods, payments for goods, salary, business trips etc., and general accounting
3) Research Support and International Affairs
   Preparation of grant application documents, presentation of research findings, project designs and agreement for collaborative research work, application for and management of patents (in conjunction with the office for Intellectual Property), etc…
4) Public Relations
   Public relations, advertisement, management of home page, support of international visitors, organization of international conferences, etc.

iv) Decision-Making System

- It is vital to provide the Institute Director with sufficient authority to work toward restructuring the university system and management based on his multi-year experience and interactions within the U.S. academic community. Examples of areas in which such authority is needed are: researcher recruitment, joint-research with top-class research institutes, rigorous evaluation processes of research findings and plans, research expenditures, and personnel salary compensation.
- The Institute will be established as an organization under the direct management of the president of the Kyushu University. The system will be set up for the Institute Director to be able to make decisions on research plans, research framework, and budget implementation in consultation with the Steering Committee that consists of the Institute Director and program area leaders (science advisors) and any other additional members that the Director may invite as deemed appropriate.
- The Director will be assisted by the Associate Director. An External Advisory Committee

composed of national and international figures in the field will review the Institute annually and provide input and recommendations.

v) Allocation of authority between the center director and the host institution's side

- The appointment/dismissal of the Institute Director and authorization for employment of the Principal Investigators must be authorized by the head of the host institution, the President of Kyushu University. The Institute Director has the authority for the other administrative operations such as the human resource management and the implementation of budget.

(4) Researchers and Other Center Staff

i) The "core" to be established within the host institution :

a) Principal Investigators (full professors, associate professors or other researchers of comparable standing)

	Numbers		
	Beginning	End of FY 2010	Final Goal (month, year)
Researchers from within the host institution	16	16	16 (March, 2011)
Foreign researchers invited from abroad	11	11	11 (March, 2011)
Researchers invited from other Japanese institutions	3	3	3 (March, 2011)
Total principal investigators	30	30	30 (March, 2011)

b) Total members

	Numbers		
	Beginning	End of FY 2010	Final Goal (Date: month, year)
Researchers (Number of foreign researcher□ and their percentage)	71 (21, 30%)	92 (36, 39%)	130 (54, 42%)
Principal investigators (Number of foreign researchers and th□ir percentage)	30 (11, 37%)	30 (11, 37%)	30 (11, 37%) (March, 2011)
Other researchers (Number of foreign researchers and their percentage)	41 (10, 24%)	62 (25, 40%)	100 (43, 43%) (March, 2014)
Research support staff	32	37	51 (March, 2013)
Administrative staff	23	23	23 (March, 2011)
Total number of people forming the "core" of the research center	126	152	204

ii) Collaboration with Other Institutions

- To achieve success, collaborative and coordinated research efforts central to the mission of the Institute will be conducted in partnership with faculty and staff at other national and international institutions. This activity will involve not only research collaboration but also exchange of personnel. Regular meetings of all team members will take place through use of internet conferencing tools. Broadening the research base from Kyushu University will further promote the Institute activities and help establish it as center of excellence.

① Satellite Institution: University of Illinois at Urbana-Champaign, USA

- The University of Illinois at Urbana-Champaign is a top-world institution in the field of hydrogen energy and materials research in the USA. In addition to conducting Institute related research,

the Satellite Institution will serve as the base for identifying and engaging key research programs and faculty at national and international universities and institutions. As Director of the Institute, Professor Sofronis will also serve as the Director of the Satellite Institute. In this latter capacity he will report directly to the Dean of the College of Engineering at the University of Illinois. Appropriate agreements between Kyushu University and the University of Illinois, other than an exchange of students which is already in place, will be negotiated if the Institute is funded. Both parties have expressed interest and support for establishing this satellite institute at the University of Illinois.

②Cooperative Institutions

- We envision engaging in collaborative research with distinguished scientists from internationally recognized institutions. This includes site visits to facilitate research by leveraging research capabilities. Key institutions are the following:
  - Tohoku University (JPN)
  - Atmosphere and Ocean Research Institute of the University of Tokyo (JPN)
  - National Institute of Advanced Industrial Science and Technology (JPN)
  - University of California, Berkeley (USA)
  - Massachusetts Institute of Technology (USA)
  - Sandia National Laboratories (USA)
  - Imperial College of London (UK)
  - Swiss Federal Institute of Technology Zurich (SUI)
  - Tsinghua University (China)
  - Dalian Institute of Chemical Physics, Chinese Academy of Sciences (China)

(*5) Research Environment*

1) Provide an environment in which researchers can devote themselves exclusively to research by exempting them from other duties and providing them with adequate staff support to handle paperwork and other administrative functions.
   - In order for Institute researchers to focus exclusively on their research, we will employ an efficient and competent administrative office to execute the all required administrative work needed for a world-class Institute. This will involve planning of the Institute's budget, purchasing of equipment and goods, procurement procedures, business trips procedures and preparation support, grant application preparation and submission processes, support for presentations, assistance for joint research projects and launching of new initiatives, handling of contracts, patent applications, publications processes, and facilitating visitors. We are determined to build a strong support infrastructure so that the Institute can pursue its mission with no hindrances whatsoever.
   - In addition, we will consistently work toward improving the skills of the technical staff employed in the support of research operations, facilities maintenance, and equipment.
   - Furthermore, we plan to decrease the teaching academic load for the Institute researchers and set up a rewards system for teaching substitutes.

2) In order to facilitate Institute researchers and invited researchers from external institutions to focus on their research—with no need for immediate engagement on grant application preparation for research funding
   - We will provide the necessary research facilities and equipment as possible so that the researchers can start and/or continue their research. We are also planning to set a system such that the Institute Director can decide and provide initial research funding to the researchers as deemed appropriate.

3) As a rule, fill postdoctoral positions through open international solicitations.
   - To recruit well-qualified post-doctoral research associates, advertisements for the positions will be placed on the Kyushu University website, the Kyushu University Offices overseas in Great Britain, California, Washington D.C., Munich, Korea, Beijing, etc., at the

Satellite Institute's website in Illinois, and major international academic magazines and related magazines in Japan. The recruitment process will be supervised by the Institute Director in consultation with the Steering Committee. The corresponding recruitment practices at the University of Illinois will be used on all Institute research personnel hiring.

- The Kyushu University has already carried out a recruitment campaign for its projects on "Young Researcher's Independent Research Environment Maintenance and Promotion Program" and "Next Generation Research Training Program."

4) Establish English as the primary language for work-related communication and appoint administrative personnel who can facilitate the use of English in the work process.
   - We will adopt English as the primary language for work-related communications.
   - In order to foster an English-speaking environment, we will employ administrative office personnel from Kyushu University who are fluent in English.
   - Periodic training opportunities will be offered for the administration work force.
   - The Administrative Office will oversee the translation from English of the expenditure supporting documents for business trips, purchasing goods, salary compensation, and daily life activities in order to make the daily life of non-Japanese people at the Institute as easy as possible.

5) Adopt a rigorous system for evaluating research and a system of merit-based compensation.
   - As stated in the document delineating the Institute Director's vision, all aspects of the Institute shall be evaluated on an annual basis, or more frequently if deemed necessary by the Director, by the External Advisory Committee. The Committee will review all aspects of the Institute, including the leadership and management, the research progress being made in each activity, and the plans for new initiatives. The Committee will provide the Director with a written report on their findings and recommendations.
   - Based on the recommendations of the External Advisory Committee and input from the Steering Committee, the Institute Director will plan the allocation of research funds and salary adjustments to cultivate and foster a productive research environment by rewarding success.
   - Kyushu University currently has a system in place that sets salary ranges based on individual researcher contributions to the interests of the University. As Institute needs and activities begin to arise, the Kyushu's salary system will be re-examined.

6) Provide equipment and facilities, including laboratory space, appropriate to a top world-level research center.
   - The Kyushu University is relocating its campus to Ito on the western part of Fukuoka. This relocation decision was made to serve our new strategic goal for an open university at the forefront of cutting edge research in an educational institution.
   - Currently, the Ito Campus houses the International Research Center for Hydrogen Energy, the Research Center for Hydrogen Industrial Use and Storage (HYDROGENIUS), and the Inamori Frontier Research Center. The Ito Campus is indeed a unique place with the largest Hydrogen Research Institute in the world for hydrogen related cutting edge research and facilities.

   - In order to continue developing its research environment and visibility toward becoming a world renowned institution, Kyushu University, under an initiative by the president, plans to build a research facility with cutting edge equipment specifically for this WPI program in the Ito Campus. While building the facility, we will be able to provide accommodations or laboratories for the WPI Institute's national and international researchers.
   - We will ensure sharing of open space and laboratories amongst researchers from various fields to encourage open meetings, discussion, and debate.
   - We also plan to promote exchange and discussion among Kyushu University, Satellite Institute, and collaborating institutions through video-teleconferencing.

7) Hold international research conferences or symposiums regularly (at least once a year) to

bring the world's leading researchers together at the center.

- For the last four years, we have held the "International Hydrogen Energy Development Forum" once a year at Kyushu University, Fukuoka. World leaders in their fields of expertise have presented their work and have interacted with the scientific and industrial community of Japan.
- By capitalizing on the experiences gained from organizing this Global Forum, we are confident that we will easily organize and host international conferences and specialized workshops with active participation from world famous researchers and institutions on a regular basis and on all aspects of the research activities of the Institute. Examples of conference and symposia themes are hydrogen energy and fuel cells, hydrogen production by photocatalytic water splitting, sustainable material conversion systems, innovative CO_2 capture, CO_2 geological storage and ocean sequestration, and system economic analysis and evaluation.
- By fostering information exchange, vigorous debate, and exploration of new initiatives and collaborations, these conferences and workshop presentations will assist the Institute in its mission to contribute to the society' efforts on countermeasures for global warming.

8) Other measures to ensure that top-caliber researchers from around the world can comfortably devote themselves to their research in a competitive international environment, if any.

- We have four university facilities available to accommodate invited national and international researchers. We have also made arrangements for private apartments designated for university use. Comfortable and fully-furnished accommodations will be provided for invited researchers so they may concentrate on their research activities.

(6) Indicators for Evaluating Institute's Global Standing

- As stated in the Director's vision statement, indicators and metrics for evaluating the Institute's standing and visibility are i) the quality and impact of journal publications; ii) the extent of joint publications as demonstration of the enabling value of the Institute; iii) invited keynote and plenary lectures; iv) symposia organization in international conferences by Institute researchers; v) trend-setting workshops that attract participation of national agencies such as MEXT, JSPS, U.S. NSF, U.S. DOE, European Commission; vi) organization of international conferences and participation of the Institute's researchers in international conferences; vii) invitations to the Institute's researchers for participation in government panels and national laboratory efforts; viii) patents and technology accomplishments; and x) the numbers of visitors to the Institute, especially, the visitors from overseas is a key indicator of the Institute's visibility.
- The Director, in consultation with the Steering Committees and External Advisory Committees, will coordinate actions to be taken for the Institute to achieve and maintain excellence. This includes prompting the principal investigators to enhance their visibility and hence, the Institute's visibility by taking action on all Institute standing indicators listed above. In particular, international awards for Institute researchers and the number of article citations the Institute's work receives will be used as a metric to evaluate overall standing and visibility. In this regard, a particularly revealing index of the Institute's quality will be considered the degree of citation of the work of young faculty and researchers—it is well known that it usually takes some time for young faculty to get their work recognized. Lastly, funding for program areas will be commensurate to the individual area's level of participation in the Institute's activities to meet its goals and visibility as a world premier institution.

- The primary goal by the time of the interim evaluation (5 years from the Institute inception) is that the Institute has established its reputation as an international center of excellence for fundamental research toward meeting its mission for a carbon-neutral energy society. Indicators for meeting this goal shall be well recognized breakthroughs in fundamental research (e.g., discovery of how hydrogen promotes fatigue of materials or discovery of new catalysts for material transformation through asymmetric oxidation). Such breakthroughs on fundamental science will allow the Institute to expand its second term mission objectives (6^{th} to 10^{th} year) to include directions addressing technology development.

The 10-year overarching goal is the completion of fundamental research for technology

development. By way of example, specific goals include design of new alloy for hydrogen resistant materials, new alloys for on-board hydrogen storage, technologically viable production of hydrogen through artificial photosynthesis, new low-cost catalysts for fuel cells, and demonstration projects for ocean- and geo-sequestration of carbon.

(7) Securing Research Funding

- Past record: The research funding acquired by Japanese principal investigators in the past five years is as follows:
  - Fiscal 2005: 3.7 million dollars
  - Fiscal 2006: 21.7 million dollars
  - Fiscal 2007: 24.6 million dollars
  - Fiscal 2008: 29.2 million dollars
  - Fiscal 2009: 28.5 million dollars

- Prospects after establishment of the center:
  - The total amount of research funding acquired by main Japanese Principal Investigators in the past five years is over 21.5 million dollars per annum on average. The goal is to leverage the Institute for more funding to be secured in the coming years.

Others

- The activity of this research Institute will continue after the end of the grant period. Institute research will continue to be promoted since we expect that the scientific breakthroughs over the next 10 years will open new research pathways associated with the impact from technologies developed by the Institute's research contributions.
- The concept and project of this research Institute will be promoted as an example of the internationalization of research and education mission of the Kyushu University as described by the present-year mid-term goals and strategic plans of Kyushu University. The research environment of this Institute, in which world-leading researchers collaborate, will remain and similar research activities which serve national and social needs will spread through the entire Kyushu University.
- This Institute is the first example of a foreign researcher to be selected as the Institute Director. It is expected that other units and organizations of the Kyushu University will benefit from the academic administration system of this Institute, which will be morphed according to the academic stature of the Institute Director. We expect that the Institute mode of operation will serve for the entire Kyushu University as a role model for recruiting researchers, establishing and promoting international collaborations with top-class research institutions, vigorous peer evaluation of research and faculty productivity, allocation of research resources and personnel financial compensation according to academic qualifications, scientific visibility, and established research record, etc.