

Summary of Proposal

Host institution name	Kyushu University
Head of host institution	Setsuo Arikawa (President, Kyushu University)
Center director	Petros Sofronis
Administrative director	Takaaki Kurasaki
Title of center project	Carbon-Neutral Energy Research Institute: The Grand Highway for a Carbon-Neutral Energy Fueled World
Center name	International Institute for Carbon-Neutral Energy Research, Kyushu University
Project Summary	To provide sufficient energy for future generation requires a holistic approach to energy production, storage and usage that utilizes renewable resources, is sustainable and leaves no carbon footprint. Success requires rapid technological breakthroughs of unprecedented magnitude in numerous disciplines. The proposed Carbon-Neutral Energy Research Institute based on hydrogen seeks to determine the fundamental nature of these barriers and to discover solutions to overcoming them. Challenges facing implementation include production of sufficient quantities of hydrogen, delivery and storage of the hydrogen and capture and sequestration of any CO ₂ generated during the production process. The Institute at Kyushu University along with the satellite institute at the University of Illinois will provide the facilities and environment needed to foster the inter- and multi-disciplinary research between national and international scientists. The leadership and management system of this Institute constitutes a paradigm shift for Japanese research centers that will transform our research enterprise.
Research fields	<u>Research field:</u> Multi/Inter-disciplinary research that involves chemistry, physics, materials science, mechanics, geo-science, oceanic science, and biomimetics <u>Significance of the proposed project:</u> The impact of global warming, the rising cost of fossil fuels as well as the anticipated decline in supply provide societal, economic and technology driving forces for developing an alternate energy source or carrier. Hydrogen gas is a potential energy carrier that could address these issues provided that technologies are developed for producing a sufficient hydrogen supply that utilizes an energy source that either does not involve generation of CO ₂ (e.g., solar or nuclear) or includes strategies for capturing and sequestering in the ocean or geologically or converting the CO ₂ to a more useful form. The importance of the proposed Institute is that it will help to develop science-driven technological solutions to enable the realization of a hydrogen-based energy economy (society) that is sustainable and environmentally friendly. The research agenda of the Institute addresses specifically the scientific barriers/challenges for efficient and low cost hydrogen production; hydrogen storage; design of hydrogen tolerant materials; efficient and reliable fuel cells; material conversion; and carbon capture, ocean sequestration and geological sequestration as well as energy-efficient conversion to more useful forms.
Research objectives	The overarching objective of the Institute is to establish the fundamental science underlying the technology of innovative, safe, and reliable systems for the production, storage and utilization of hydrogen, as well as for separation of CO ₂ , carbon oceanic and geological sequestration and conversion to more usable forms. To reach this objective requires establishing a fundamental-science understanding at the atomic level of such phenomena as adsorption, absorption, dissolution, diffusion, reaction

	<p>characterizing interaction of hydrogen and CO₂ and materials in the framework of multi-phase fluid and solid systems. The research objectives toward a carbon-neutral energy fuelled society are summarized as follows:</p> <ul style="list-style-type: none"> • Development of innovative and sustainable hydrogen production processes such as photocatalytic water splitting. • Development of hydrogen-embrittlement resistant structural materials for the design of a safe and reliable hydrogen infrastructure. • Development of next generation fuel cells through novel materials and devices. • Development of novel hydrogen storage materials with a storage capacity larger than 6wt% H₂. • Development of high efficiency waste-free material transformation processes. • Development of low-energy carbon separation and concentration processes • To inform and educate the public about the scientific benefits of CO₂ sequestration technologies and of transitioning to a carbon-neutral energy fuelled economy (society).
Outline of management	<p>The research culture and management style of the Institute are intended to be a model for restructuring the Kyushu University on the basis of the Director's academic experience in the US and the general input from prestigious international research universities and laboratories.</p> <p>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 program areas, and the budget implementation related to the management of the Institute. On all these matters the director consults the <u>Steering Committee</u> that is headed by the director and its members (science advisors) are the program area leaders of the Institute.</p> <p>A vital component of the Institute is the <u>External Advisory Committee</u> which is composed of national and international leaders in the field. This Committee reviews all aspects of the Institute annually, including the leadership and management, the research progress being made in each program area, and the plans for any initiatives.</p> <p>The Director is assisted by the <u>Associate Director</u> for the management of the Institute' research activities. The Office of the Director is supported by the <u>Administrative Director</u>, head of the office of the Institute's <u>Management Department</u> whose purpose is to provide administrative support to the research personnel of the Institute. The official language of the Institute's Management Department is English.</p> <p>The Director of the Institute, Professor P. Sofronis, is a faculty member at the University of Illinois at Urbana-Champaign. A satellite office will be established at Illinois to serve as the hub for collaborations in the US and to strengthen international research activities.</p>
Researchers and other center staffs	<p>We plan to have 30 Principal Investigators (11 researchers from overseas), 130 researchers (54 researchers from overseas), and a total of 204 research scientists by the end of 2013.</p> <p>Main Principal Investigators: P. Sofronis, Y. Murakami, T. Katsuki, Y. Naruta, T. Ishihara, C. Adachi, A. Takahara, S. Ogoh, K. Kusakabe, Z. Horita, N. Nakashima, Kazunari Sasaki, E. Akiba, M. Okada, T. Yanagi, B.P.Somerday, L. Schlapbach, R. Ritchie, H. L. Tuller, L. J. Gauckler, J. A. Kilner, P. Chen, C. A. Chen.</p> <p>Partnering institutions for collaborative research are: Tohoku University (JPN), University of Tokyo (JPN), National Institute of Advanced Industrial Science and Technology (JPN), University of Illinois (USA), 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), and Dalian Institute of Chemical Physics (China).</p>

<p>Outline of research environment</p>	<p>To drive the research mission and to ensure each program area 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.</p> <p>The Director will organize a program review meeting on an annual basis and, in addition to the members of the External Advisory Committee, will invite leading scientists and engineers in each of the thematic areas to review the entire program, including the leadership and management of the overall Institute. The Principal Investigators of each funded program will present the achievements of their program, describe synergistic activities with other members of the Institute and with partnering institutions, and conclude with planned future activities. The program review committee will provide a written evaluation of the achievements and future plans of each effort. The Director, in consultation with the External Advisory Committee and Steering Committee, will use these evaluations to determine future funding for each program and theme. The Institute will organize international conferences, symposia, and specialized workshops to engage the scientific community from academia, industry, and national laboratories and to inform the society on the benefits of a carbon-neutral energy fueled world.</p> <p>To facilitate research at the Institute, the Kyushu University will build a new facility with equipment for cutting edge research</p>
<p>Outline of indicators for evaluating the Institute's global standing</p>	<p>The Institute's visibility and global standing will be measured by i) the quality and impact of the Journal publications, especially joint publications; ii) invited, keynote, and plenary lectures at international conferences; iv) symposia organization in international conferences by Institute researchers; v) trend setting workshops and symposia that attract participation of national agencies such as MEXT, JSPS, US NSF, US DOE, European Commission; vi) 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.</p> <p>Lastly, an indicator of the Institute's international outreach will be the number of international visitors and international researchers in residence at Kyushu for an extended period of time.</p>
<p>Securing research funding</p>	<p>Amount of the research funding won by the main Principal Investigators over the past five years is over 21.5M dollars per annum on average. Similar level of funding is expected for the coming years.</p>
<p>Summary of host institution's commitment</p>	<p>The university's strategic vision is summarized in: "position the university as a center of global research and education" and "promote the development of new academic fields by pursuing multi/inter-disciplinary research through fostering an academic environment that attracts excellent researchers." In this framework, the Kyushu University will embrace and support the Institute with all its resources. More specifically, the Kyushu University will enthusiastically: i) assist to establish the Institute's administrative structure for research and budget implementation; ii) work with departmental units to accommodate participating researchers in the Institute; iii) revise the internal system so that English is the language for international affairs, and iv) re-examine the personnel compensation system.</p>

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	<p><CENTER PROJECT></p> <ul style="list-style-type: none"> ○ 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 CO₂ 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 CO₂ 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 CO₂ 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, CO₂ separation and concentration, and geological storage and ocean sequestration of CO₂. 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 CO₂. 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 CO₂ under extreme pressures; iii) the triple-phase rocks/water/CO₂ interactions and the stability of geological traps; iv) the interaction of supercritical CO₂ with ocean turbulence in order to predict how ocean weather affects the efficiency of CO₂ 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 CO₂ 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 CO₂ 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.

<RESEARCH ORGANIZATION>

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.

<PROJECT MANAGEMENT>

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.

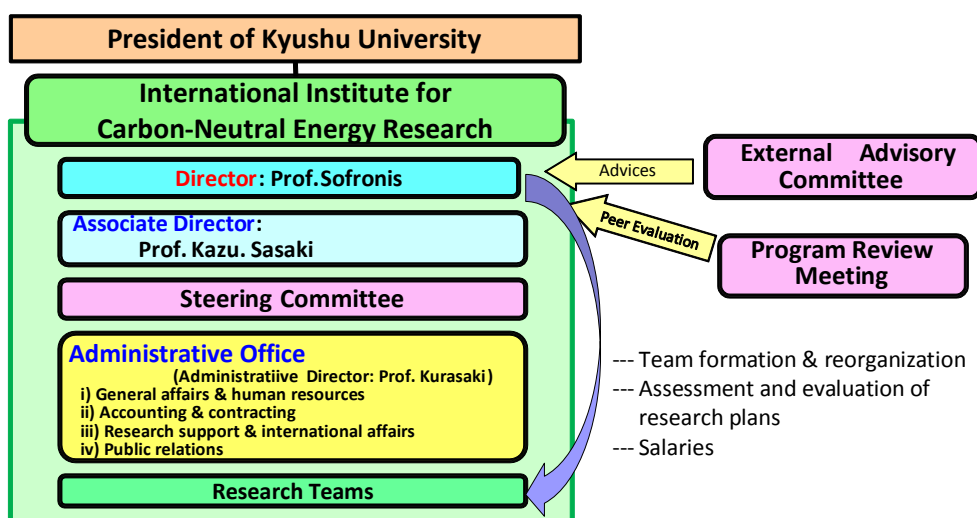


Fig. Administrative structure of the Institute

<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.

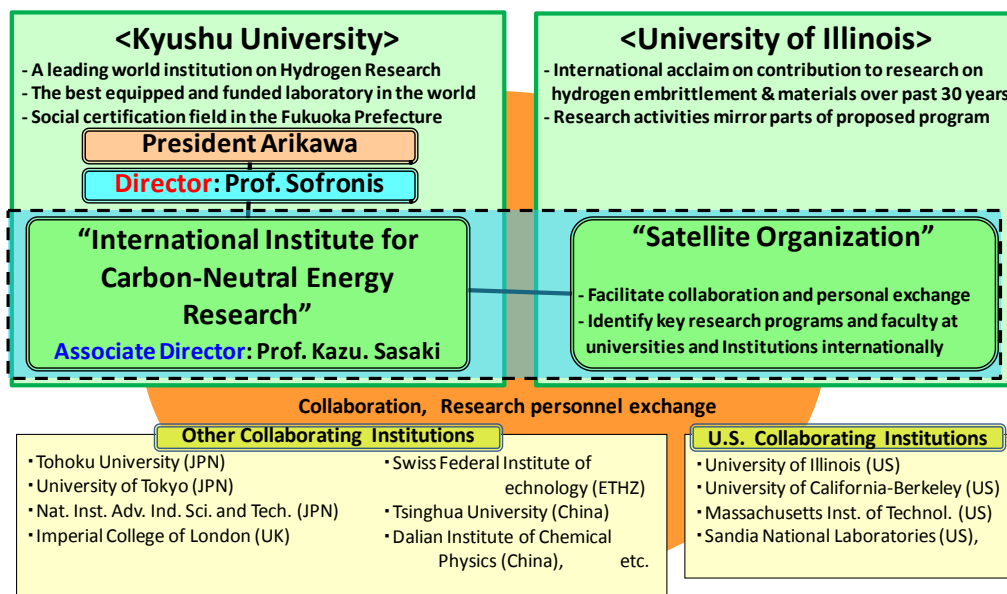


Fig. Collaborations with other institutions

(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 CO₂ 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 CO₂ 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.

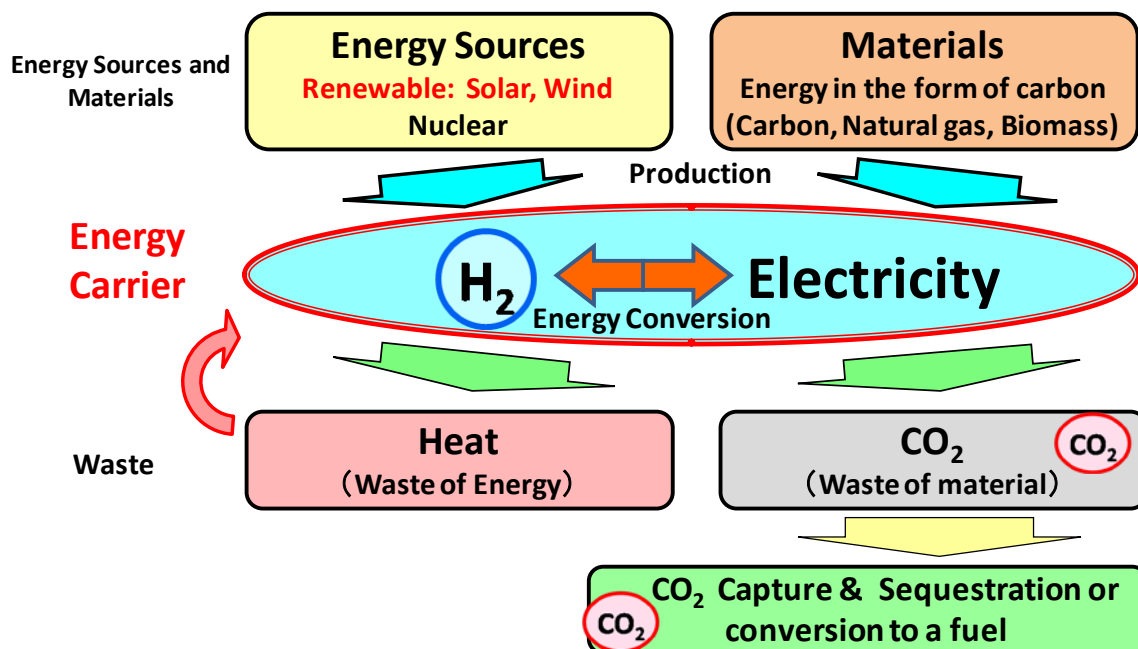


Fig. A Carbon-Neutral Energy Fueled System

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 CO₂ emission from the energy utilized in a CCS process exceeds the actual CO₂ 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 CO₂ 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 CO₂ 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 CO₂ storage capacity and the physicochemical behavior of CO₂ 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 CO₂. 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 CO₂ separation and concentration, CO₂ 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 CO₂ 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 CO₂.
 - 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% H₂;
 - 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 CO₂ geological and ocean sequestration by understanding CO₂ behavior;
 - Increase public awareness for hydrogen technologies and long-term CO₂ behavior in each earth and ocean;

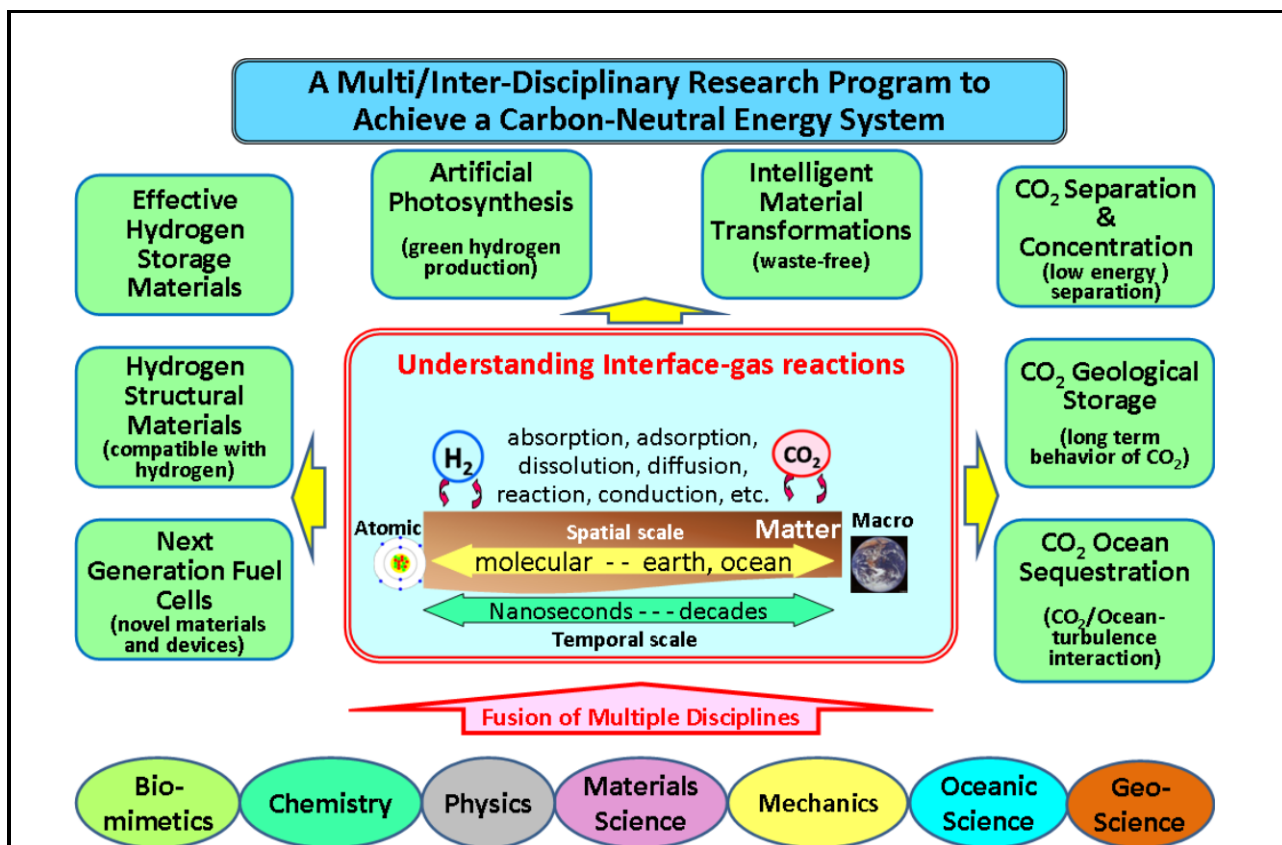


Fig. Interfaces in this multi/inter-disciplinary research program in the Carbon-Neutral Energy Research Institute

<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 CO₂ 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 CO₂ to functional compounds in combination with electrolytic techniques mimicking dark reactions.
- Our research will contribute to the development of a hydrogen production technology without CO₂ emission and the conversion of CO₂ 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 CO₂ under extreme pressures

- Development of hydrogen and CO₂ storage technologies requires the knowledge of fundamental thermophysical properties of hydrogen and CO₂ 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% H₂ 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% H₂.

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 CO₂. 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 CO₂ photoreduction catalyst system; and iii) activation system of hydrogen, oxygen, water, nitrogen and CO₂, 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 CO₂ separation and concentration systems: toward an efficient and low cost CO₂ separation and concentration technology

- Currently, a large number of methods exist for the separation of CO₂ 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 CO₂ in membranes and develop a highly efficient and low-cost electrochemical CO₂ separation process.
- We propose that a CO₂ absorption process be used in conjunction with water electrolysis through ion exchange membranes, where CO₂ 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 CO₂.
- 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 CO₂ storage groups.

8) CO₂ geological storage: understanding CO₂ behavior in underground reservoirs and the development of numerical prediction models

- CO₂ 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 CO₂ geological storage, and as a consequence issues related to the dissolution and trapping of CO₂ to water, oil, rocks and coals in highly pressurized porous layers, and CO₂ 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 CO₂ at the triple phase boundary of rocks/coals, water/oil and CO₂ in micropores under high pressure. We will also investigate the microbial CH₄ conversion mechanisms. The ultimate goal is to develop a

numerical simulation tool for CO₂ diffusion, by testing and evaluating the diffusion behavior of CO₂ from the underground reservoirs to the ground surface including both saturated and unsaturated layers.

9) CO₂ Ocean sequestration: informing the public on ocean sequestration

- Ocean absorption helps to naturally remove CO₂ from the atmosphere; however, due to the ever-increasing rate of CO₂ emission into the atmosphere, we are at a stage where the rate of CO₂ emission exceeds the removal rate. In order to meet CO₂ emission reduction targets, CO₂ 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/CO₂ 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 CO₂ and the impact on the oceanic and global environments. Further we will analyze and determine the risks of CO₂ 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 CO₂ 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 CO₂ 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 CO₂) 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 CO₂, 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; CO₂ 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 resources 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 CO₂ capture, CO₂ 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's 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 (6th to 10th 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.

Center Director's Vision

International Institute for Carbon-Neutral Energy Research
— The Grand Highway for a Carbon-Neutral Energy Fueled World —
Multi/Inter-disciplinary research on the interface between hydrogen/CO₂ and matter

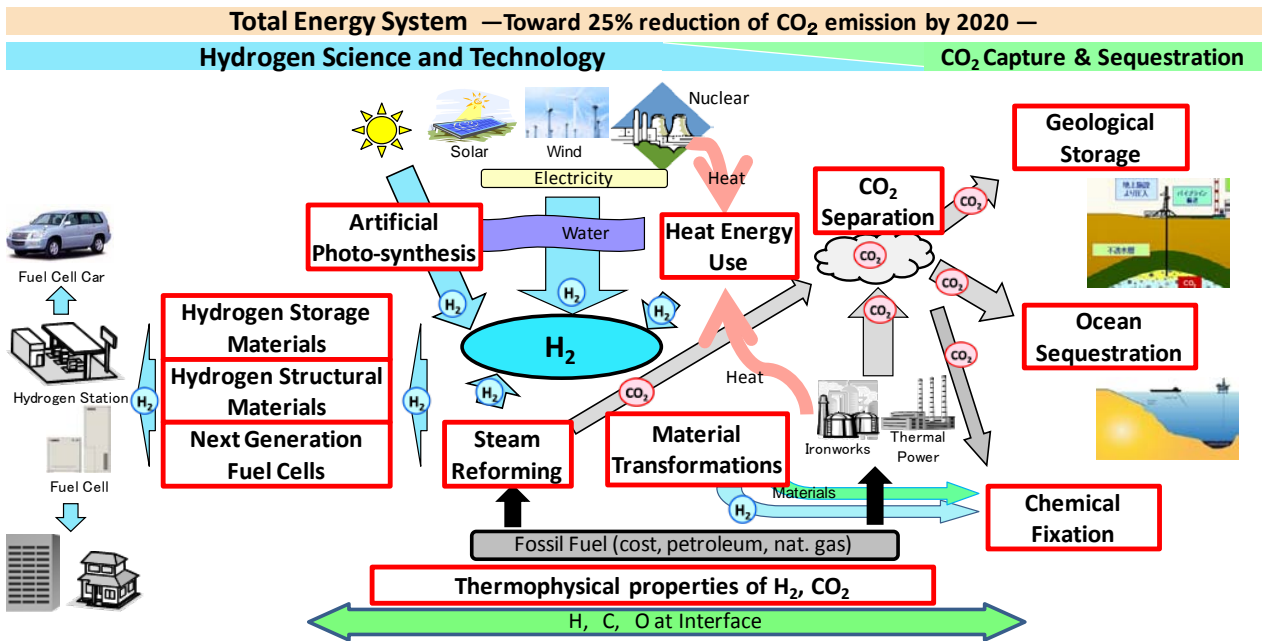
April 23, 2010
Petros Sofronis
Professor
University of Illinois

<Summary>

Achieving and even exceeding CO₂ emission reduction targets requires not only strategies for capturing and either sequestering or converting CO₂ to a useful fuel but also developing high efficiency and effective methodologies for producing an alternate energy carrier such as hydrogen gas. The challenges require a paradigm shift in our approach to research that bridges not only multiple spatial, molecular to miles, and temporal scales, nanoseconds to decades, but it also necessitates bringing together scientists and engineers from disparate disciplines such as chemistry, materials and geoscience to work cooperatively and synergistically. The International Institute for Carbon-Neutral Energy Research will provide the foundation, environment and framework to stimulate novel research endeavors between leading experts in diverse research fields such as chemistry, physics, materials science, mechanics, geoscience, oceanic science and biomimetics. The Institute activities will lead to fundamental science discoveries underlying the development of innovative, safe, and reliable systems for the production, storage and utilization of hydrogen as a fuel in a hydrogen-based economy as well as for either capture and storage of CO₂ or its conversion to a useful product. In addition, it will provide the nation and the international community with the next-generation of scientists and engineers needed to address such complex and critical technological and societal challenges.

The approach that will be adopted will be integrative multi- and inter-disciplinary that focuses on physical chemistry and dynamics to discover, control and manipulate the interactions between materials and hydrogen or CO₂, which will lead to hydrogen production and material transformation with no CO₂ emission; hydrogen storage materials; hydrogen embrittlement resistant materials; high efficiency fuel cells; and safe carbon capture, ocean sequestration and geological storage or efficient conversion of CO₂ to CO and O. The ultimate vision for the Institute is to create and use hydrogen as a fuel that enables the realization of a carbon-neutral energy fueled society through Green Innovation.

The Institute will be launched by the Kyushu University in collaboration with the University of Illinois at Urbana-Champaign. Both institutions are internationally recognized centers for research in the area of hydrogen and materials. An agreement for student and faculty exchanges between the two universities was signed in 2008.



1. Preface

There is no more opportune time for the Kyushu University in collaboration with the University of Illinois at Urbana-Champaign to mount such an unprecedented international effort for an institute on carbon-neutral energy. The Kyushu University is a leading world institution on hydrogen research and fuel cell technology. Its institute for hydrogen industrial use and storage is the best equipped and funded laboratory in the world for research on hydrogen-induced degradation and materials for the next generation fuel cells. The prefecture of Fukuoka is well known for its strong support for sciences and its ability to move rapidly and put science in the use of society by developing new technologies. The University of Illinois research contributions to research on hydrogen embrittlement and materials over the past 30 years have won it international acclaim. Significantly there is an agreement already in place between the Kyushu University and the University of Illinois for student and research personnel exchange. All these factors warrant a sustained institutional and local government support for research at the planned International Institute for Carbon-Neutral Energy Research by a team of researchers with recognized research records and ongoing collaborations. Such a sustained research environment and commitment to quality research will enable the Kyushu Institute to attract and engage world-class researchers in all fields of its mission.

More specifically, success of the Institute requires that it:

- Has a well-defined vision and a strategic plan to achieve its mission and goal
- Attracts and supports world-class researchers, both nationally and internationally.
- Provides its researchers with the facilities and tools needed to achieve the research goals
- Establishes a management and administrative plan that fosters multi- and inter-disciplinary research.

The grand vision of the Institute is to produce and distribute efficiently and effectively a fuel that ultimately leaves no carbon footprint. To achieve this vision requires

addressing several grand challenges including the efficient production of hydrogen, ideally using energy sources and processes that generate no harmful emissions; capture and sequester or convert to fuel any CO₂ generated by the production or use of the fuel; delivery and storage systems to enable effective use of hydrogen as an energy carrier; as well as design and construction of high-efficiency fuel cells for applications in a hydrogen-based economy.

To address the technological challenges and to accomplish the mission, the Institute must provide the resources, facilities and environment to attract and retain top scientists and engineers, both nationally and internationally, from a wide range of science and engineering disciplines. Additionally, the Institute will establish collaborative programs, including joint research efforts with national and international research institutions and universities that will involve not only collaborative efforts but a two-way exchange of personnel.

The Director will provide leadership and overall management of the Institute. To assist the Director, Steering Committee and External Advisory Committees will be established. Key members of the Steering Committee will be program area leaders (science advisors) although the Director may invite additional members as deemed appropriate. The External Advisory Committee will be 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 the leadership and management, the research progress being made in each activity, and the 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 will be the responsibility of the Director.

The Institute will promote the activities and achievements of the Institute through an annual progress report which will describe research highlights, significant accomplishments and future directions, newsletters to highlight achievements on a more regular basis, scholarly publications in internationally peer-reviewed journals, participation and organization of symposia at international meetings as well as a biannual workshop at Kyushu University or a partnering research institution.

A more detailed description of each of these topics is provided in the following sections.

2. Critical Research Initiatives

The impact of global warming, the rising cost of fossil fuels as well as the anticipated decline in supply provide societal, economic and technology driving forces for developing an alternate energy source or carrier. Although these issues are vital to the future well-being of Japan, success has global societal and economic implications. Moving to and implementing a non-fossil based energy carrier system, especially one in which the production is independent of foreign sources, is highly desirable. Hydrogen gas is a potential energy carrier that could address these issues provided that methodologies are in place for producing a sufficient hydrogen supply that utilizes an energy source that either does not involve generation of CO₂ (e.g., solar or next generation nuclear systems) or includes strategies for capturing and sequestering in the ocean or geologically or converting the CO₂ to a more useful form. To make a hydrogen-fueled economic system viable, the scientific and engineering challenges of delivering and using hydrogen will need to be overcome. This means that materials with a high tolerance to hydrogen-induced degradation will need to be developed for production, delivery and application systems; effective and efficient hydrogen storage media will need to be developed for a multitude of

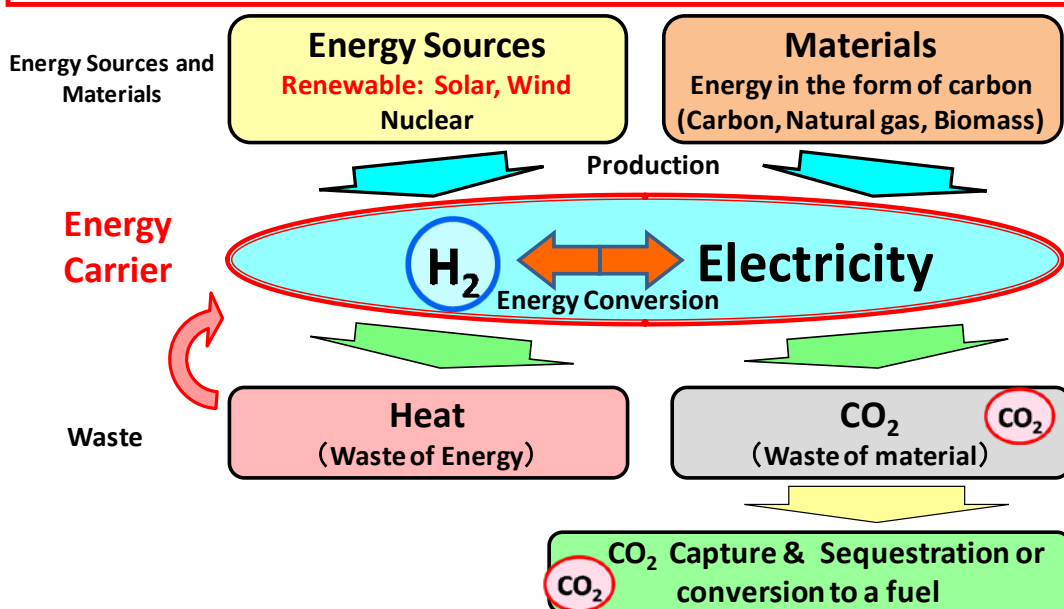
applications and the efficiency of fuel cells will need to be increased.

Hydrogen has several attractive features as an energy carrier that could remove our dependence on fossil fuels and at the same time reduce the levels of CO₂ that are being produced. For it to be a truly carbon-neutral energy source, methods for producing large quantities of hydrogen using energy sources that either generate no CO₂ or are used in conjunction with CO₂ capture technologies need to be developed. The mission of the Institute will be to develop science-driven technological solutions to enable the realization of a hydrogen-based energy economy that is sustainable and environmentally friendly. Therefore the research agenda of the Institute emphasizes critical issues in the areas of: hydrogen production; solid-state hydrogen storage; hydrogen tolerant materials; efficient and reliable fuel cells; material transformation; CO₂ capture, ocean sequestration and geological storage as well as energy-efficient conversion to more useful forms.

Furthermore, it is essential to understand the various phenomena occurring at the interface between materials and hydrogen, oxygen, and CO₂ (and their underlying mechanisms) to enable the scientific and engineering breakthroughs needed to realize a carbon-neutral energy fueled society. The Institute activities must be broad based, bridging multi-dimensional spatial (atoms to molecules to crystals, to geological formations and to oceanic systems) and temporal (nanoseconds to many tens of years and beyond) scales.

Carbon-Neutral Energy Fueled Society

- Burning of fossil fuels and biomass produces CO₂ and waste of energy as **heat**
- **Hydrogen** is an **energy carrier** that can be produced from various sources (e.g., solar, carbon)
- Non-fossil based energy system as a solution to global warming, rising costs, declining of oil supplies, energy security, and independence by converting hydrogen to electricity with **minimum CO₂ production and waste of energy**



3. Outline of research activities

The Kyushu Institute's approach to science necessary for the development of a

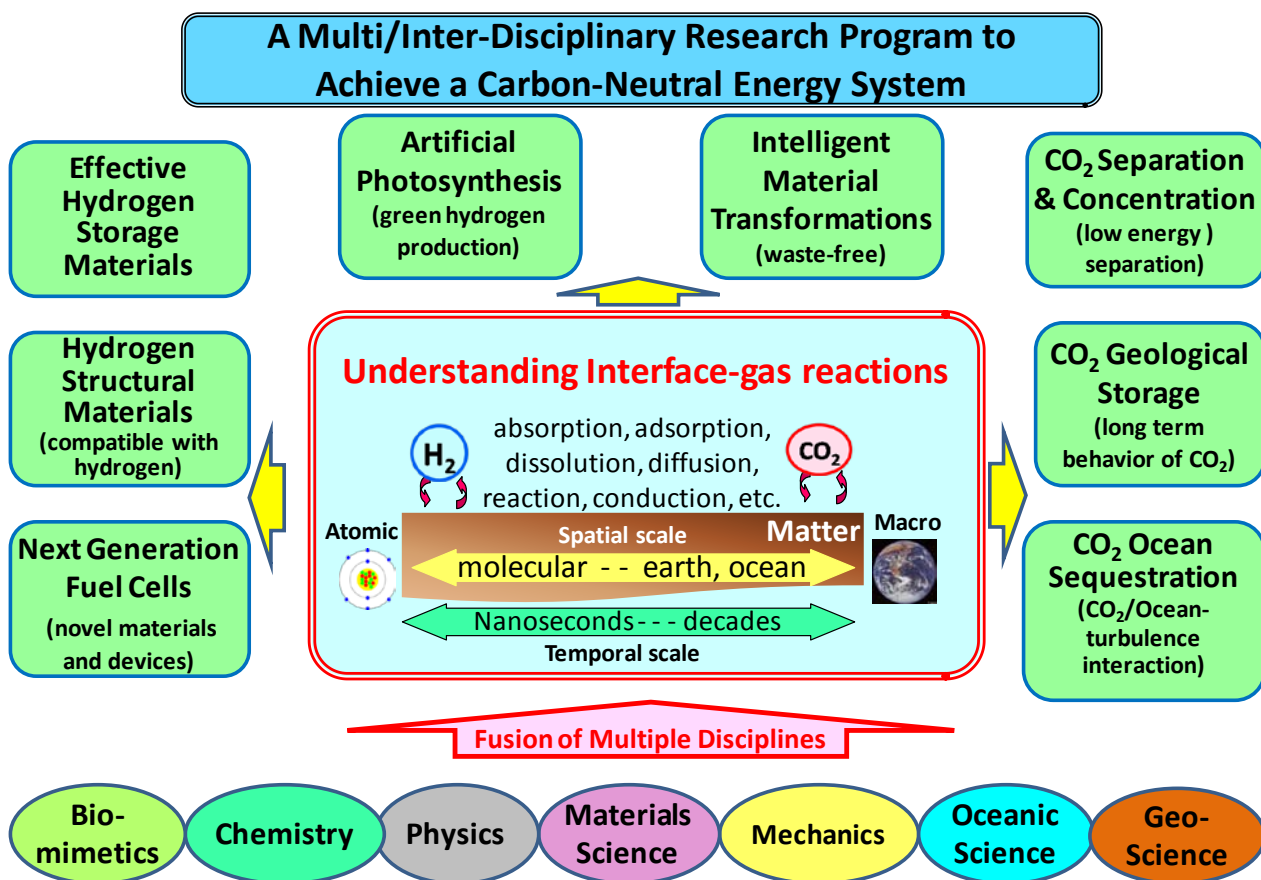
carbon-neutral energy fueled society will be to cross-cut disciplinary boundaries through a judicious integration of information from atomistic/microscopic/macrosopic time and length scales for phenomena occurring at the interface of chemistry, physics, materials science, mechanics, geoscience, oceanic science, and biomimetics. The global nature of this challenge is obvious and we will launch a “International Institute for Carbon-Neutral Energy Research” to work toward establishing it as the global leader for this work.

To achieve our mission of developing an carbon-neutral economy that is sustainable and at the same time is environmentally friendly – key criteria for addressing global warming and finding an alternate to fossil-based fuel systems – the following research themes have been identified. The concept of the interface between hydrogen/CO₂/oxygen and matter is pervasive throughout all research themes. The research topics identified initially as being critical to the move toward a sustainable, earth-friendly hydrogen-based economy are:

- Artificial photosynthesis through autocatalytic water splitting.
 - Toward green hydrogen production.
- Structural materials compatibility with hydrogen.
 - Toward designing a safe and reliable hydrogen infrastructure.
- Materials for the next generation fuel cells.
 - Toward establishing the fundamentals for high efficiency energy conversion and the development of new devices.
- Fundamental thermophysical and flow properties of hydrogen, CO₂ hydrates, and carbon dioxide under extreme pressure conditions, e.g. 100MPa.
 - Toward elucidating the hydrogen/matter interactions over a broad range of temperatures and pressures and the stability of supercritical CO₂
- Hydrogen storage materials
 - Toward designing an effective hydrogen storage system.
- Intelligent chemical transformations and catalysis.
 - Toward developing waste-free material transformation.
- Advanced CO₂ separation and concentration processes.
 - Toward the development of an efficient CO₂ separation and concentration technology.
- CO₂ geological storage.
 - Toward understanding the underground behavior of CO₂, e.g. chemical interactions and stability among three phase of CO₂, water and rock.
- CO₂/Ocean-turbulenece interactions for ocean sequestration.
 - Toward understanding CO₂ behavior in ocean.
- Energy efficient and environmentally benign approaches to conversion of CO₂ to CO and O and then to a usable energy form.
 - Toward a carbon-neutral energy fueled society.

The research program must be multi- as well as inter-disciplinary. In addition, it must couple synergistically theory, computer modeling and simulation with experimental methodologies that utilize state-of-the-art approaches to explore solid-gas interactions at appropriate length and time scales. Here it is envisioned that the efforts will be coordinated such that the experiments inform model development and the predictions of the models are verified by appropriate experiments. Additionally, computer simulations and models will be employed to enhance the interpretation of experimental observations. For example, *ab initio* calculations might be used to determine the change in the electronic states on surfaces and in the interior to enhance our understanding of the initial adsorption and dissociation of hydrogen on the surface, which could accelerate development of a

solid-stage light-weight hydrogen storage medium or to ascertain the tolerance of internal interfaces to hydrogen, which could suggest how to create a microstructure with low sensitivity to high-pressure hydrogen environments.



4. Research objectives

The overarching objective of the Institute 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 transformation), as well as for separation of CO₂, carbon oceanic and geological sequestration and conversion to more usable forms. To reach this objective 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 multi-phase fluid and solid systems. By publically disseminating our research findings we expect and aspire to contribute to the societal discourse on the scientific soundness of ocean sequestration and geological storage. Thus, the research objectives toward a carbon-neutral energy fueled society can be summarized as follows:

- Development of innovative and sustainable hydrogen production processes, such as photocatalytic water splitting.
- Development of hydrogen resistant alloys for the design of a safe and reliable hydrogen infrastructure.

- Development of the next generation fuel cells through research in novel materials and devices.
- Development of novel hydrogen storage materials with a storage capacity of over 6wt% H₂.
- Development of high efficiency material transformation processes without any by-products such as waste and CO₂.
- Development of low-energy carbon separation and concentration processes by investigating the mechanisms of CO₂ absorption.
- Educate the public about the scientific aspects of ocean sequestration and geological storage so that the society decides on the benefits of moving toward a carbon-neutral energy fueled world on the basis of sound scientific information.

5. Research organization and cooperation with related institutions

(1) Research organization

The research organization will be theme based. Four broad-based divisions are envisioned initially: Hydrogen Production, Delivery and Utilization; Hydrogen Storage; CO₂ 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.

(2) Cooperation with other institutions

To achieve success in our mission, 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 collaborations but also exchange of personnel. Regular meetings of all team members will take place through use of internet conferencing tools. This capability may also be used to deliver and broadcast important research meetings between partnering institutions. Broadening the research base from Kyushu University will further promote the Institute activities and help establish it as Center of Excellence in this area.

(Satellite Institution)

- University of Illinois at Urbana- Champaign, USA.

The Director of the Institute, Professor P. Sofronis, is a faculty member at the University of Illinois at Urbana-Champaign 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 office will serve as the base for identifying and engaging key research programs and faculty at Universities and Institutions nationally and internationally. As Director of the Institute, Professor Sofronis will 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.

(Collaborating Institutions)

We envision to engage 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)
- High Energy Accelerator Research Organization (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 (ETHZ)
- Tsinghua University (China)
- Dalian Institute of Chemical Physics, Chinese Academy of Sciences (China)

6. Research evaluation and visibility

The Director will organize a program review meeting on an annual basis and, in addition to the members of the External Advisory Committee, will invite leading scientists and engineers in each of the thematic areas to review the entire program, including the leadership and management of the overall Institute. This meeting will be convened at Kyushu University. It is envisioned that the science advisor of each theme will present an overview of the activities, highlighting specific achievements and challenges, as well as describing future research directions and activities. The Principal Investigators of each funded program will present the achievements of their program, describe synergistic activities with other members of the Institute and with partnering institutions, and conclude with planned future activities. The form of these presentations may be oral or in poster format. The program review committee will provide a written evaluation of the achievements and future plans of each effort. The Director, in consultation with the External Advisory Committee and Steering Committee, will use these evaluations to determine future funding for each program and theme. The final decision about program funding level will be made by the Director of the Institute.

Metrics of the Institute's visibility will be considered i) the quality and impact of the 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 and symposia that attract participation of national agencies such as MEXT, JSPS, US NSF, US DOE, European Commission; vi) 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.

7. Institute management

One of the goals of the Institute is to be a model for 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's 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 the 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 conduct of the research activities, the formation and composition of the research program areas or clusters, and the budget implementation related to the management of the Institute. On all these matters the Director consults the Steering Committee that is headed by the Director and its members (science advisors) are the program area leaders of the Institute.

A vital component of the Institute is the External Advisory Committee which is 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 the leadership and management, the research progress being made in each activity, and the 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 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 office 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.

8. Closure

We propose a research Institute with a mission to carry out fundamental science for the removal of the technical barriers toward a carbon-neutral energy fueled society. The

objective of the Institute is to develop the science required for the realization of a hydrogen economy and enable the technological breakthroughs required for efficient CO₂ capture and sequestration in both the ocean and the earth. Research topics include artificial photosynthesis for hydrogen production, efficient fuel cell catalysis, hydrogen storage and development of hydrogen resistant alloys, interaction of CO₂ with ocean turbulence and geological formations, and thermodynamics and chemistry of crystalline and supercritical CO₂. The disparate length and time scales involved in these phenomena range from the electron to that for oceans and geo-formations and this necessitates approaches that judiciously bridge the temporal and spatial scales. The research will be interdisciplinary and will cross-cut the boundaries of chemistry, physics, materials science, mechanics, geoscience, oceanic science, and biomimetics. The effort will be international and will involve industry and national laboratories. The Institute will operate in accordance to the highest academic standards and through a rigorous peer evaluation and review process. We expect that the scientific discoveries of the Institute will result in the reduction of the societal carbon footprint and the removal of barriers to a carbon-neutral society.

Host Institution's Commitment

Date : November 12, 2010

To MEXT

Name of host institution : Kyushu University

Name and title of head of host institution : Setsuo Arikawa, President

Signature

I confirm that the measures listed below will be taken faithfully if "International Institute for Carbon-Neutral Energy Research" is adopted under the World Premier International Research Center Initiative (WPI).

<Provision in host institution's mid-to-long-term plan>

- Describe clearly the host institution's mid-to-long-term strategy plan and how the center is positioned within that strategy.
- Details of the mid-term goal and strategy plans for Kyushu University from the year 2010 are as follows;
 - Mid-term goal: "Kyushu University will undertake research activity as a global research and education center, and reflect the results to the social development. We will have our academic environment in a high-quality and attractive condition, where excellent researchers will gather and share/grow their knowledge. The university contributes to the development and creation of a new research area of integrated sciences."
 - Mid-term strategy plans for this goal are: "To promote the research and development activities on the subjects which are in national and social demands, and to attain creative and advanced research results by taking advantage of feature of a university."; "To undertake interdisciplinary and world leading researches in a wide range of subjects, from humanities and social sciences to natural sciences and engineering, for attainment of outstanding achievement."; and "To establish a research organization which can promptly, flexibly, and appropriately respond to the social needs of the times."
- The concept of Carbon-Neutral Energy Research Institute is in close line with this new mid-term goal and plans of Kyushu University. The Institute is organized directly under the president of Kyushu University, and the support to the Institute Director Prof. Sofronis from the University President and from the whole departments of Kyushu University will be guaranteed.

<Concrete Measures>

- Describe the concrete measures that the host institution will take to satisfy the following requirements.
- (1) How it will support the center's need to secure resources that match or exceed the project grant through such means as competitive grants obtained by researchers participating in the project, in-kind contributions and other forms of assistance by the host institution (including partial payment of salaries, provision of research space), and/or external donations.
- In order to acquire large competitive research grants, Office for Strategic Research Planning and other related offices of Kyushu University will proactively support researchers, such as on information gathering and strategic advice on grant applications. In addition, the university funding will be effectively used to provide financial support to researchers.
- For the provision of the world's top-level research environment, a new research building for the WPI project with advanced equipments and facilities will be constructed in the new ITO campus, under initiative of the university president. Prior to the completion of the construction of this new building, research rooms and spaces will be arranged for invited or newly employed researchers from external organizations.
- The Institute will proactively act on the attainment of financial supports from the local government and industries in related areas.
- (2) How it will institute a system under which the center's director is able to make substantive personnel and budget allocation decisions necessary to implementing the center project—a system, which in practice, allows the center director autonomy in making decisions regarding the center's operation.

○ The Institute will be established as an organization directly under the president of Kyushu University. The system will be set up for the Institute Director to be able to make decisions on research plans, research frameworks, budget implementation, that are related to the Institute management, with the exceptions for the appointment/dismissal of the Institute Director and authorization for employment of the Principal Investigators.

(3)The support it will provide to the center director in coordinating with other departments within the host institution when recruiting researchers for the center, while giving reasonable regard to the educational and research activities of those departments.

- In regards to the researchers in Kyushu University contributing to the project, the university will work in coordination with the parent departments, providing them with the supports for the employment of substitutes for their educational and research activities, in order to maintain the educational and research activities of the parent departments.
- The university will provide flexible research infrastructures where international and national top-class researchers can perform collaborative researches which reflect the social requirements.

(4)Its flexibility in applying, revising, or supplementing the host institution's internal systems as needed for the center to effectively implement new management methods (e.g., English-language environment, merit-based pay, top-down decision making) unfettered by conventional modes of operation.

- Kyushu University is currently implementing a project for internationalization of research and education in the University, under the initiative of the president. As a part of this plan, efforts have been made, in collaboration with International Affairs Division of Kyushu University; conducting undergraduate and postgraduate degree programs in English language; increasing the number of international students and lecturers, preparing internal documents and the university webpage in English; assisting students and staff members to improve their English language skills; establishing international student and researcher support centers at every campus, in order to further accelerate the establishment of international educational and research environments.
- The Institute will be established as an organization directly under the president of Kyushu University. The system will be set up for the Institute Director to be able to make decisions on research plans, research frameworks, budget implementation, which are related to the institute management.
- In regards to salary settings, there is already a system in Kyushu University to set the various range of salary based on the abilities of researchers especially for ones from external institutes. As needs arise, the system will be re-examined.
- In addition, Kyushu University will work in cooperation with the Institute for flexible implementation, adjustment, modification of the university's internal systems, upon the requests from the Institute Director, in order to ensure smooth management of the Institute.

(5) Its accommodation of the center's infrastructural requirements (for facilities, e.g., laboratory space; equipment; land, etc.).

- For the provision of the world's top-level research environment, a new research building for the WPI project with advanced equipments and facilities will be newly constructed in the new ITO campus, exclusively, under initiative of the university president. Prior to the completion of the construction of this new building, research rooms and spaces will be arranged for invited or newly employed researchers from external organizations.
- In ITO campus, there are already many advanced research facilities and equipments in the research centers, for example the Central Analytical Center and High Voltage Electron Micrograph Laboratory, and the preferential usages of those equipments will be arranged for the researchers in the WPI project.

(6) Other types of assistance it will provide to give maximum support to the center in achieving its concepts and objectives and becoming a world premier international research center in both name and deed.

- Prof. Yukitaka Murakami, Vice Director of the Institute, will take on responsible roles as the chief center-project officer for this WPI research Institute, to realize the concepts and to meet the objectives of the Institute. After the establishment of the Institute, he will continue to take on responsible roles as the chief center-project officer under the direction of the president of Kyushu University, in order to effectively work in coordination with the relating departments of the

university.

- The promotion of the concept of this Institute as the model project for internationalization of research and education in Kyushu University, and the application of the concept of this Institute to the entire University body would contribute to reforming the university system and to training our young researchers to be internationally recognized.

List of Principal Investigators

Name	Current affiliation (organization, department)	Academic degree
1 Petros Sofronis	University of Illinois, Department of Theoretical and Applied Mechanics (US)	Ph.D., Micromechanics of materials, Environmental degradation of materials
2 Yukitaka Murakami	Kyushu University	Dr. of Eng., Materials mechanics, Metal fatigue, Hydrogen energy
3 Tsutomu Katsuki	Kyushu University, Institute for Advanced Study	Dr. of Science, Sustainable chemical transformation, Catalysis
4 Yoshinori Naruta	Kyushu University, Institute for Materials Chemistry and Engineering	Dr. of Science, Catalysts, Inorganic chemistry
5 Tatsumi Ishihara	Kyushu University, Department of Applied Chemistry	Dr. of Eng., Catalyst and solid state electrochemistry
6 Chihaya Adachi	Kyushu University, Department of Applied Chemistry	Dr. of Eng., Materials science and device physics
7 Atsushi Takahara	Kyushu University, Institute for Materials Chemistry and Engineering	Dr. of Eng., Surface and Interface Characterization
8 Seiji Ogo	Kyushu University, Department of Applied Chemistry	Dr. of Science, Green Chemistry

9	Katsuki Kusakabe	Fukuoka Women's University, Department of Living Environmental Science	Dr. of Eng., Reaction engineering, Catalyst
10	Zenji Horita	Kyushu University, Department of Materials Science and Engineering	Ph.D., Dr.of Eng., Materials Science
11	Naotoshi Nakashima	Kyushu University, Department of Applied Chemistry	Ph. D., Nanocarbon science, Supramolecular science
12	Kazunari Sasaki	Kyushu University, Department of Mechanical Engineering	Fuel cell materials, Inorganic materials
13	Etsuo Akiba	National Institute of Advanced Industrial Science and Technology, Energy Technology Research Institute	Dr. of Science, Materials science
14	Braian P. Somerday	Sandia National Laboratory (US)	Ph. D., Materials Science and Engineering
15	Masuo Okada	Tohoku University, Department of Materials Science	Ph. D., Hydrogen absorbing alloys, Functional ceramics
16	Louis Schlapbach	Federal Institute of Technology Zurich(ETH)(Swiss)	Ph. D.,Materials Science and environmental science
17	Robert O. Ritchie	University of California, Berkeley, Department of Materials Science and Engineering (US)	Dr. of Sc., Structural materials, Ceramic/metal interfaces
18	Harry L. Tuller	Massachusetts Institute of Technology (US)	Eng.Sc.D., Functional electroceramic materials
19	Ludwig J. Gauckler	Swiss Federal Institute of Technology (SUI)	Dr. of Sc.,Nonmetallic Inorganic Materials
20	John A Kilner	Imperial College London (UK)	PhD., Materials for solid oxide fuel cells and electrolyzers

21	Ping Chen	Dalian Institute of Chemical Physics (China)	Ph. D., Materials Chemistry
22	Saburo Matsuoka	Kyushu University, Department of Mechanical Engineering	Dr. of Eng., Fatigue and fracture of materials
23	Yoshiyuki Kondo	Kyushu University, Department of Mechanical Engineering	Dr. of Eng., Strength of Materials
24	Joichi Sugimura	Kyushu University, Department of Mechanical Engineering	Dr. of Eng., Tribology and Machine Design
25	Yasuyuki Takata	Kyushu University, Department of Mechanical Engineering	Dr. of Eng., Thermal Engineering
26	Xing Zhang	Tsinghua University (China)	Ph.D., Thermal Science
27	Masaki Minemoto	Kyushu University, Department of Chemical Engineering	Dr. of Eng., Mass and Heat Transfer, Fluid Dynamics
28	Tetsuo Yanagi	Kyushu University, Research Institute for Applied Mechanics	Dr. of Sc., Physical Oceanography
29	Chen-Tung Arthur Chen	National Sun Yat-sen University (Taiwan)	Ph. D, Marine biogeochemistry, Ocean acidification, global change