Energy Outlook

International Institute for Carbon-Neutral Energy Research

JANUARY 2015

Collaboration between Japanese and US academic and research institutions is providing carbon-neutral energy solutions

Japan-U.S. Collaboration on Energy

I²CNER Tokyo Symposium

December 12, 2014

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I^{2}CNER Tokyo Symposium

Japan-U.S. Collaboration on Energy

The I^{2}CNER Tokyo Symposium, which was held on December 12, 2014, focused on the following topics: i)How Japan-U.S. collaboration on carbon-neutral energy solutions impacts each country, and more broadly, the world; ii)How merging 2 different research cultures is transforming multi-disciplinary international research infrastructure; iii)What we can do to influence energy policy and direction through our collaborative research. The symposium was attended by representatives from government, the U.S. Embassy, and energy industries.

Opening Remarks / Greetings

Chiharu Kubo

President of Kyushu University

Explained that he expects I^{2}CNER to act as a bridge between Japan and the U.S.. He also emphasized the positive, transformative effect he expects I^{2}CNER to have on the research culture of Kyushu University as a whole.

Sadayuki Tsuchiya

Deputy Minister of the Ministry of Education, Culture, Sports, Science and Technology

Stated the significance of hosting a joint Japan-U.S. symposium on energy because both play leading roles in solving the world's energy problems. He also expressed his great hope for future international recognition of I^{2}CNER.

Toshio Kuroki

WPI Program Director

Offered an overview of the WPI program and the support plan for the WPI centers' fundamental scientific research, which includes large-scale and long-term funding. He also expressed his optimism about the future of I^{2}CNER.

Caroline Bouvier Kennedy

U. S. Ambassador to Japan

Emphasized the importance of the scientific exchanges between Japan and the U.S.. She also stressed that Prof. Sofronis is a key member in the field of clean energy, and his great efforts, with the support of Japan and the U.S. through I^{2}CNER, will contribute to the hydrogen economy such as spreading fuel-cell cars on the market in the future.

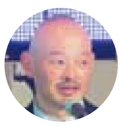
Internationalization of Scientific Research in the Search for Global Energy Solutions

Petros Sofronis

Director of the International Institute for Carbon-Neutral Energy Research (I^{2}CNER)

Introduced the approach of each of I^{2}CNER's nine divisions and presented various multi-disciplinary, international research achievements. He also discussed I^{2}CNER's innovations in academic infrastructure, such as its extensive network of top-tier international collaborating institutions and the fact that 45% of I^{2}CNER's researchers are from outside of Japan. He also stressed the importance of creating a diverse core of researchers which includes young researchers, female researchers, etc. to facilitate the establishment of an open and globally visible research platform at Kyushu University.

International Approach to Developing Technologies for Aggressive CO_2 Emissions Reduction by 2050



Kenshi Itaoka

Acting Division Leader of the Energy Analysis Research Division, I^{2}CNER, Kyushu University

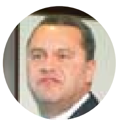
Outlined the research approach of the Energy Analysis Research Division (EAD), which has international collaboration at its core. He also presented one of the EAD's developmental scenarios to achieve a 70%-80% reduction of CO_2 relative to 1990 levels by 2050 for the creation of a carbon-neutral society. To realize this scenario, he explained the necessity of technological development in two main areas: increasing the efficiency of energy conversion and utilization, and reducing carbon intensity in the transport, industry, and household sectors.

Speakers surrounding Ambassador Kennedy

Unraveling Pore-Scale Processes Central to Safe and Reliable Geologic CO_2 Storage Through a Collaborative Numerical, Experimental, and International Approach

Takeshi Tsuji
Lead Principal Investigator of the CO_2 Storage Research Division, I²CNER, Kyushu University

Offered an overview of I²CNER's Japan-U.S. collaboration on the technology of CO_2 injection in geological reservoirs, which is a promising approach to CO_2 reduction. Prof. Tsuji emphasized that sub-seabed storage around the Japanese islands alone can store over a hundred billion tons of CO_2. Prof. Tsuji further explained one of the division's objectives, which is to characterize CO_2 behavior from the nm- to the km-scale. Using data obtained through the division's latest computational efforts, he gave clear and detailed explanations of the dependence of interactions of stored CO_2 on the geomaterial properties of the storage reservoir.



Kenneth Christensen
Principal Investigator of the CO_2 Storage Research Division, I²CNER, Kyushu University
Professor of the University of Notre Dame

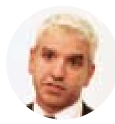
Presented his recent experimental achievements, the current state and future challenges in the evaluation of reservoir and post-injection CO_2 behavior simulations. His experiments demonstrated that the accuracy of reservoir-scale simulations depends on accurate pore-scale representations. He also emphasized the need for clarification of the factors that affect CO_2 behavior, development of measurement diagnostics to quantify the dynamics at the pore-scale, and predictions of post-injection migration.

Inspired by Nature-New Energy Sources from Hydrogenase Model Complexes

Seiji Ogo
Lead Principal Investigator of the Catalytic Materials Transformations Research Division, I²CNER, Kyushu University

Explained that platinum is generally used as an electrode catalyst of the fuel cell. However, an alternative catalyst is necessary because platinum is scarce and expensive. Hydrogenase (H_2ase) is an enzyme that extracts electrons from hydrogen gas under ambient conditions. This enzyme was tested for application to a fuel cell electrode because it surpasses platinum with regard to hydrogen activation ability. However, a problem that remains to be resolved is the stability of the H_2ase to in the presence of oxygen gas. In the second half of his lecture, Prof. Ogo used his picture book "The Story of Hydrogen Energy" to help the audience understand his presentation.

Federal Energy and Materials Policy, Opportunities for Bilateral Cooperation



Cyrus Wadia
Assistant Director for Clean Energy & Materials R&D, White House Office of Science and Technology Policy

As observed in the changes in demand for shale gas, evaluations of the value of energy resources change rapidly. Dr. Wadia explained the regulations and innovation policies of the U.S. government, and the goals and progress presented in the "The Blueprint for a Secure Energy Future," announced in 2011 for the expansion of clean energy. For example, with regard to the goal of American energy independence, as of 2012, the U.S. achieved a 10% drop in oil import rates (equivalent to one million barrels per day). In a historic move, the first-ever fuel economy standards for heavy duty vehicles were introduced, and more than one million homes were upgraded, which enabled many families to save more than $400 on their heating and cooling bills in the first year alone. Additionally, he explained the future vision of the

Panel Discussion

The discussion topics included the search for the most effective energy fusion to reduce greenhouse gases by 70% from their 1990 levels, and how Japan and the U.S. can collaborate on green energy technology, as well as I²CNER's role in this collaboration. Dr. Wadia commented on the difficulty of unifying the rules across all states in the U.S. and the challenges of controlling industries which have more CO_2 emissions. Representatives from both countries stressed the need to pursue a wide range of approaches to energy solutions, especially since the future of energy development is unpredictable. Views were also exchanged on the need for government involvement in the management of CO_2 through research grants, carbon taxes, and how to incentivize the industrial sectors to reduce CO_2 emissions.

U.S. government, which is affected by many factors, including the predictions of the increase in the world's population, climate change, localization and centralization of natural resources, technology development by 2050, the shift from fossil fuels to natural gas, and the government's tax relief in response to the capital investment in renewable energy generation. Furthermore, Dr. Wadia presented President Obama's "Material Genome Initiative," which aims at deploying new materials in technology markets twice as fast with minimal costs. Achievement of this goal, Dr. Wadia stressed, requires merging of technological innovations in Japan and the U.S.. Dr. Wadia maintained that sharing technologies and research budgets, along with collaborative research, will reinforce the cooperative relationship between the two countries; this cooperation will contribute to solving the energy problem.

The Future of CO_2 Management in Japan

Toyoki Kunitake

President of the Kitakyushu Foundation
for the Advancement of Industry Science and Technology
WPI Visiting Professor of I²CNER, Kyushu University

CO_2 concentration in the atmosphere is increasing-globally-levels are quickly approaching 400ppm. This is a universal problem that also affects global climate change. Prof. Toyoki Kunitake demonstrated the importance of CO_2 management, including two approaches to controlling CO_2: CO_2 capture and utilization and CO_2 sequestration. He introduced more than ten examples of CO_2 utilization methods, including carbonated drinks, caffeine removers, plastic, conversion to a useful chemical such as methanol, and generation of biofuel from an algae which makes oil from CO_2. In addition, he showed three examples of CO_2 capture: liquid absorption, solid absorption, and membranes. However, he explained that there is still work to be done with regard to clarification of the mechanisms of CO_2 capture and its characteristics, and the behavior of water and CO_2, both at the nm- and the km-scale. Additionally, Prof. Kunitake pointed out that due to their different environments, CO_2 management methods differ considerably between Japan and the U.S.. Considering population, population density, amount of fossil fuel resources, and the average electricity and gasoline rates of the two countries, he concluded that their different environments require different solutions; for instance, due to its smaller area, Japan would require a more efficient, higher capacity method, whereas the U.S. can sequester CO_2 on a larger scale. Also, it is convenient for Japan to convert CO_2 into other substances to compensate for its poor natural resources, whereas the U.S., with a rich supply of natural resources, would be better served by making direct use of the captured CO_2. Prof. Kunitake also introduced some of the areas in which I²CNER's Japanese and American researchers are collaborating, such as 30nm-thin membranes, CO_2 storage in reservoirs, and carbon nanotubes, as well as several projects on artificial photosynthesis funded by the Japanese government.

During the Session

Closing Remarks

Kazunari Domen

WPI Program Officer

Gave remarks about each session and stated that he expected I²CNER to set the guidelines for a carbon-neutral energy society through fundamental research, and be a bridge between Japan and the U.S. on carbon-neutral energy research.

The I²CNER Tokyo Symposium was an overall success. By bringing together representatives from the U.S. Embassy, Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan Society for the Promotion of Science (JSPS), The U.S. Department of Energy (DOE) and experts on "Green Innovation" from the Japanese government, research institutes, and industry, the symposium helped I²CNER to explore what can be done to improve, enhance, and accelerate the translation of its research to influence energy policy and directions.

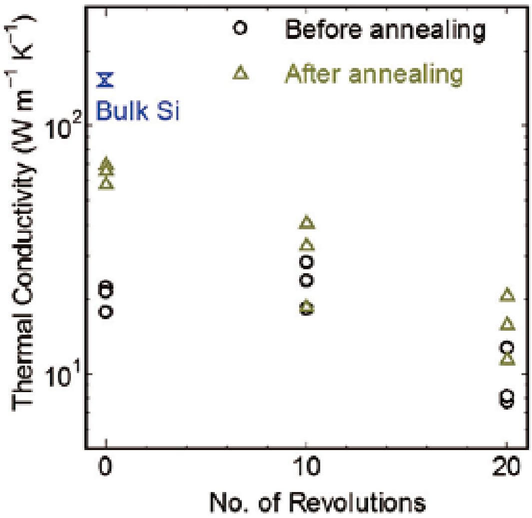
Over 20 researchers presented posters to the symposium attendees

1 Thermal Conductivity Reduction of Crystalline Silicon by High-Pressure Torsion

Sivasankaran Harish, Mitsuru Tabara, Yoshifumi Ikoma,
Zenji Horita, Yasuyuki Takata, David G. Cahill and Masamichi Kohno

Nanoscale Research Letters 2014, 9:326
DOI:10.1186/1556-276X-9-326

To improve the performance of vehicles, a key strategy is to extract a fraction of energy lost as waste heat by the exhaust gases and utilize it to produce electrical energy by integrating thermoelectric devices. It is crucial to increase the figure of merit ZT ($ZT = S^2\sigma T k^{-1}$, where S is the Seeback coefficient, σ is the electrical conductivity, T is the temperature and k is the thermal conductivity) value to improve thermoelectric performance. To achieve higher ZT, lattice thermal conductivity of the material needs to be reduced without compromising the charge carrier mobility. To limit the lattice thermal conductivity, we have demonstrated a novel strategy using high pressure torsion under a pressure of 24 GPa and room temperature. Using this approach, we show a dramatic reduction in the thermal conductivity of bulk crystalline silicon (142 $Wm^{-1}K^{-1}$) by a factor of ≈20 (~7 $Wm^{-1}K^{-1}$). Current work focusses on further reducing the thermal transport and enhancing the charge carrier mobility by using silicon germanium alloys.



Thermal conductivites of the HPT-processed before and after annealing. An order of magnitude reduction in the thermal conductivity of Si upon HPT processing is observed. Annealing of the HPT samples shows an increase in thermal conductivity due to the recerse transformation of metastable phases to Si-I cubic diamond phase.

2 Suppression of hydrogen embrittlement by formation of a stable austenite-layer in metastable austenitic stainless steel

Toshihiro Tsuchiyama, Koichi Tsuboi, Shuichi Iwanaga,
Takuro Masumura, Macadre Arnaud Paul Alain,
Nobuo Nakada and Setsuo Takaki

Scripta Materialia 2014,90-91:14
DOI:10.1016/j.scriptamat.2014.07.005

Structural steels which have both high strength and hydrogen embrittlement resistance are required for infrastructure development in a hydrogen society. Martensitic steel, widely used as a high-strength structural steel, is suceptible to serious hydrogen embrittlement, while austenitic steel, which has a high hydrogen embrittlement resistance, has a low level of strength, so it is very hard to achieve our goal as long as we use them separately. In this study, we control the distributions of martensite and austenite to emphasize the advantages of each, so-called hybridization by microstructural control. Specifically, we formed a fine austenite layer with approximetely 100 μm thickness on a martensitic steel surface to suppress hydrogen absorption from a hydrogen gas atmosphere (Fig. 1). As a result, the newly developed steel exhibits good hydrogen embrittlement resistance while maintaining very high strength (Fig. 2), which achieves our mid- and long-term goals. The result obtained in this study is serving as a research guideline to develop hydrogen structural materials.

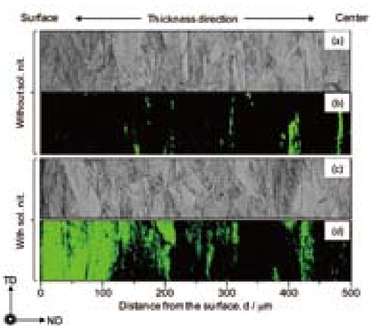


Fig. 1
Optical microstructures (a,c) and EBSD (Electron Backscatter Diffraction) phase maps (b,d) at the cross-section of the 60% cold-rolled type 304 austenitic stainless steel plates with (c,d) and without (a,b) an austenite layer. Green regions in EBSD phase maps show the austenite distribution.

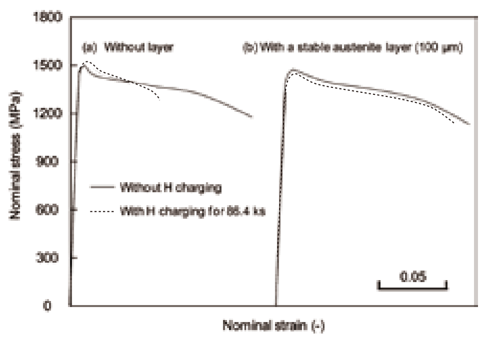


Fig. 2
Change in nominal stress-strain curves by hydrogen charging in 60% cold-rolled type 304 austenitic stainless steel plates with (b) and without (a) an austenite layer.

Research Highlights

3 Investigating the link between knowledge and perception of CO_2 and CCS: An international study

Anne-Maree Dowd, Kenshi Itaoka, Peta Ashworth, Aya Saito and Marjolein de Best-Waldhober

International Journal of Greenhouse Gas Control, Volume 28, September 2014, Pages 79–87
DOI: 10.1016/j.ijggc.2014.06.009

I²CNER is a basic research institute. However, the Energy Analysis Research Division has been conducting applied science research, not only in the engineering field, but also in the social science field, in order to determine how to enhance public understanding of low carbon emission energy technologies.

Carbon dioxide capture and storage (CCS) presents one potential technological solution for mitigating CO_2 emissions. Since CCS is a relatively new technology with associated uncertainties and perceived risks, effective methodology to communicate with the public about CCS technology needs to be developed. We examined effects of information provision on opinions of CCS implementation by providing three different information packets related to CO_2 and CCS in a public survey. With regard to changing opinions about CCS implementation, through ANOVA (see Table below), we found a clear positive effect from the information packet about CO_2 characteristics, and a clear negative effect from the information packet about CO_2 natural phenomena. Also, the information packet about CO_2 behavior in CCS influenced the public opinion of CCS implementation in a negative way. The result implies that efforts to promote understanding about CCS should incorporate information on CO_2' s characteristics, including properties and chemistry.

ANOVA on influence of information provision on opinions of CCS implementation using extent of opinion changes between the first assessment and second assessment as dependent variables

		Changes between the first assessment and second assessment		
Factors (provided information)	Statistics	Implementation country Favour (5)-Against (1)	Implementation Onshore Favour (5)-Against (1)	Implementation Offshore Favour (5)-Against (1)
CO_2 characteristics	Type III sum of squares	7.773	4.043	4.454
	F	13.537	7.168	7.485
	P-value	0.000	0.007	0.006
CO_2 natural phenomena	Type III sum of squares	3.803	4.278	4.657
	F	6.623	7.584	7.826
	P-value	0.010	0.006	0.005
CO_2 behavior in CCS	Type III sum of squares	2.447	2.631	1.404
	F	4.261	4.664	2.360
	P-value	0.039	0.031	0.125

Note)
- Positive effect $P<0.01$
- Positive effect $P<0.05$
- Negative effect $P<0.01$
- Negative effect $P<0.05$

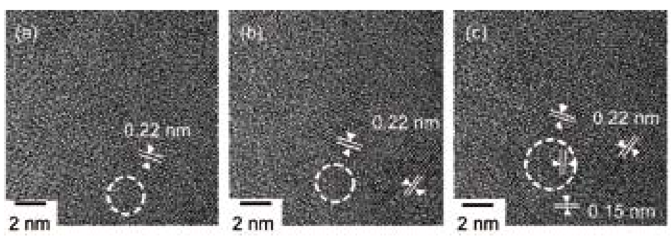
Whether positive or negative is judged by sign of mean of change in each variable

4 In situ observation on hydrogenation of Mg-Ni films using environmental transmission electron microscope with aberration correction

Junko Matsuda, Kenta Yoshida, Yukichi Sasaki, Naoki Uchiyama and Etsuo Akiba

Appl. Phys. Lett. 105, 083903 (2014)
DOI: 10.1063/1.4894101

In situ transmission electron microscopy (TEM) was performed to observe the hydrogenation of Mg-Ni films in a hydrogen atmosphere of 80-100 Pa. An aberration-corrected environmental TEM with a differential pumping system allowed us to reveal the Angstrom-scale structure of the films in the initial stage of hydrogenation: first, nucleation and growth of Mg_2NiH_4 crystals with a lattice spacing of 0.22 nm in an Mg-rich amorphous matrix of the film occurs within 20 s of the start of the high-resolution observation, then crystallization of MgH_2 with a smaller spacing of 0.15 nm happens after approximately 1 min. These results indicate that Mg_2Ni accelerates the hydrogenation of Mg, and contribute to understanding the hydrogenation mechanism of Mg-Ni films. Moreover, this study is the first successful observation of the lattice image of hydride formation in the world. Our in situ TEM method is also applicable to the analysis of other hydrogen-related materials.



Cross-sectional TEM images of a Mg_6Ni film with a thickness of 70 nm observed in an 80 Pa hydrogen atmosphere at room temperature: (a) 40 s after the start of electron beam irradiation; (b) 100 s after the start of irradiation; and (c) 140 s after the start of the irradiation. Note that an amorphous portion surrounded by a dotted circle in (a) changes to crystalline in (b), and the crystal is grown to 2 nm or more in a diameter in (c). The lattice spacing of 0.22 nm and 0.15 nm is attributed to (222) plane of Mg_2NiH_4 and (002) plane of MgH_2, respectively.

5 Proton Conductivity Control by Ion Substitution in a Highly Proton-Conductive Metal-Organic Framework

Masaaki Sadakiyo, Teppei Yamada and Hiroshi Kitagawa

Journal of the American Chemical Society 2014,136:13166
DOI:10.1021/ja507634v

Rational control of proton conductivity in solids is important for fuel cell applications. Proton transport normally occurs through hydrogen-bonding networks consisting of water molecules. However, there are few reports on control of proton conductivity by changing structures or components of the hydrogen-bonding networks, because the structure is generally unclear in polymer electrolytes due to their amorphous nature. In this study, we succeeded in controlling proton conductivity in a metal-organic framework (MOF)which has crystalline proton-conductive pathways, by cleavage of the hydrogen-bonding network by ion substituion (Fig. 1). The potassium ion-substituted MOF showed two orders lower conductivity around 10^{-4} S cm^{-1} than the ammonium one (~10^{-2} S cm^{-1}) (Fig. 2). This result contributes to the understanding of the proton transport phenomena in electrolytes and the creation of novel electrolyte materials.

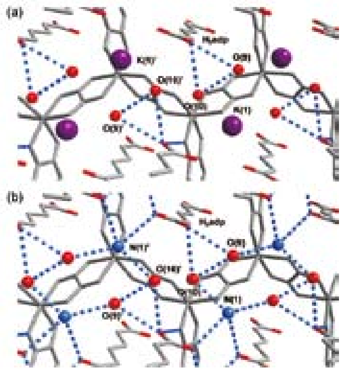


Fig. 1
Hydrogen-bonding networks in MOFs
(a) K^+-substituted MOF, (b) NH_4^+ including MOF

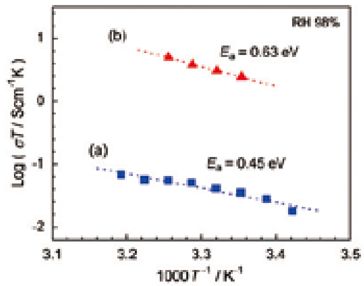


Fig. 2
Arrhenius plots of conductivity (a) K^+-substituted MOF, (b) NH_4^+ including MOF

6 Semiconducting single-walled carbon nanotubes sorting with a removable solubilizer based on dynamic supramolecular coordination chemistry

Fumiyuki Toshimitsu and Naotoshi Nakashima

Nature Communications 5, Article number: 5041
DOI: 10.1038/ncomms6041

Highly pure semiconducting single-walled carbon nanotubes (SWNTs) are essential for highly efficient electronic devices, such as in photovoltaic applications. However, contamination by metallic SWNTs and other carbon materials reduces the efficiency of their associated devices. We designed and synthesized supramolecular coordination complex-type solubilizers that enable simple and efficient separation of semiconducting- and metallic SWNTs. Using the difference of the solubility of these solubilizers, which wrap SWNTs, we readily separated semiconducting SWNTs. Furthermore, the complex-type solubilizers on the SWNTs were simply removed by adding protic acid and inducing depolymerization to the monomer components. This study opens a new stage for a large-scale purification of highly pure semiconducting-SWNTs for next-generation energy-efficient devices.

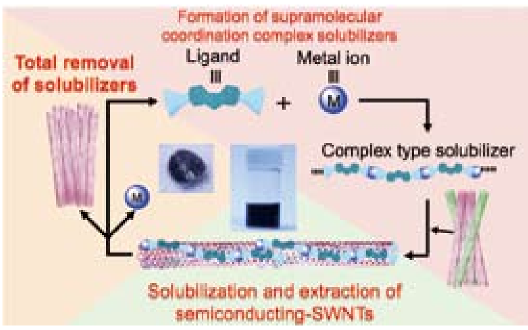


Fig. 1
Schematic illustration of the purification cycle of the semiconducting-SWNTs using a supramolecular coordination complex.

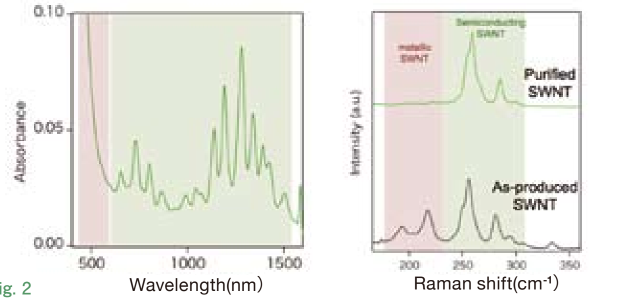


Fig. 2
Vis-near IR absorption spectrum of extracted purified semiconducting-SWNTs (left) and the Raman spectra of SWNTs before and after the purification (right).