International Institute for Carbon-Neutral Energy Research

Energy Outlook

July. 2013

World Premier International Research Center Initiative

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Discussing the future of energy

Dr. Toyoki Kunitake

WPI Visiting Professor, International Institute for Carbon-Neutral Energy Research (I²CNER)

President, Kitakyushu Foundation for the Advancement of Industry Science and Technology

Dr. Petros Sofronis

Director, International Institute for Carbon-Neutral Energy Research (I²CNER)

Professor, University of Illinois at Urbana-Champaign (US)

Petros Sofronis: Professor Kunitake, what I would like to do today is to have a discussion about your vision on energy, especially renewable energy in Japan, because as you know, we are an energy institute, and we want to invest our efforts to come up with solutions that are targeting the CO_2 emissions reduction. So the discussion that I would like to have with you is to get your wisdom, to get your opinion, to hear your expertise about where we are going as far as renewable energy is concerned. Let me start by asking you what the future of renewable energy is.

Toyoki Kunitake: This is a really difficult question....

PS: Yes, let me put it differently. Again, it is about the future of renewable energy. For instance, as far as I know, in the US, there is investment in renewable energy, but in the US, cost is a primary factor for success. If an energy approach isn't cost effective, it cannot thrive. So how is the situation in Japan?

TK: Well we have a similar situation. Renewable energies are always more expensive than oil of course, so I think that the government offers subsidies at this stage. Probably a big example is solar panels. The conversion efficiency of the solar energy is 10%, but the theoretical maximum is 25%. If the efficiency is doubled, the situation could change a lot. So I think that improved technology should help the expanded use of renewable energy, especially for solar energy.

PS: So as you point out, efficiency is an important issue, because once you double the efficiency, essentially we will have a breakthrough regarding solar energy.

Thoughts on fossil fuels

PS: Now what about fossil fuels? In the twenty-first century, what do you think is the standing of fossil fuels vis-à-vis renewable energy? Can we operate our societies and our economies without a line of fossil fuels, or will it be a mix? For instance, in the U.S. the approach is "all of the above". Fossil fuels will play a role. Renewable energy will play a role.

TK: Well, we have heard a lot about the limit of fossil fuels in the past 50 years. Many people claimed that we will be in a very serious situation in the 21st century after 40 years of the-Club-of-Rome prophecy. But it didn't happen. We have shale oil now. So I think that fossil fuels play a similarly important role in the foreseeable future, especially in Japan. We don't have fossil fuel. We have to buy it from far away, so it costs a lot for transporting it. That means that the US and Japan have very different situations in the cost of fossil fuels. You have your own. So until Japan, in the far future, can recover methane from hydrate from the bottom of the sea… until that time, fossil fuel could be expensive in Japan.

PS: I see. Regarding the use of fossil fuels, how do you perceive carbon capture and sequestration (CCS)? Should we pursue the best science we can carry out to enable technologies to capture and perhaps utilize the CO_2 if we want to have carbon emissions reduction? Is there a serious bottleneck that we should be concerned about?

TK: There are two extreme situations here. One is the release of CO_2 in huge amounts from power plants or steel mills. In that case sequestration is important, because CO_2 is concentrated already. The other extreme is CO_2 from other "diffuse" sources such as transportation and agriculture. Most of the CO_2 in this case is difficult to capture. For this second case, efficient fuel consumption is required for CO_2 reduction, and perhaps artificial photosynthesis or genetically engineered photosynthesis will help in the long term.

PS: Very interesting. So in your opinion, those are technologies that may be disruptive in the future. We need to invest in making our systems more energy efficient. As for artificial photosynthesis, although we cannot see immediate results, there may be a successful approach in the years to come.

TK: Yes. We have a huge supply of CO_2 to displace globally. How can we collect it? We cannot do it—it's not so easy. It's very expensive to do it mechanically. But for natural plants, it's easy. Plants can absorb CO_2. And also, we can use dispersed artificial catalysts in combination with solar energy to help with CO_2 reduction. It's a combination of dispersed energy and dispersed material resource (CO_2).

Renewable energy applications in Japan

PS: Speaking of the solar panels and energy production for Japan, let me come with, perhaps, an out of the box idea. What about having solar panels on platforms around the country out in the ocean? For instance, Japan is a mountainous country, so there is no room to have the solar panels around to get the energy from the sun. What about having them on floating platforms in the oceans?

TK: It's expensive.

PS: It's expensive, right? So it costs a lot—cost comes up again.

TK: Still, a lot of farmland is not used for farming. So there is room for many panels in the countryside. And that area is much less expensive. But on the ocean, it's expensive.

PS: Speaking of the ocean, what about the offshore wind farms? Those turbines that can be linked to the electric grid?

TK: I think the problem is that how to transport the energy from offshore locations 20-30 km away. It's too far away to the land. So I think we have to wait for superconductive transmission coil for carrying the electricity from far away, because that's a much more efficient way than using copper wire.

PS: So this is a technology, for instance, that I^{2}CNER may expand upon in the future.

TK: There is lots of electricity loss over a long distance, it is huge.

Advice for the next generation of graduate students

PS: Now, one question that I would like to ask you is related to the nature of our Institute. We are a university environment here and we have graduate student researchers in our program. Do you have any advice for the graduate students, and more broadly speaking, for the younger generation? How should they configure their education in order to be best-positioned to go out into the society and meet their ambitions, and of course be useful, contributing members of society? If we think about what the energy future is, then what type of education will the energy future require?

TK: Well, I graduated from Pennsylvania, I got a PhD there. So I have experienced the US system as well at graduate school, along with the Japanese system. The US system emphasized training much more. The Japanese system used to be based on apprenticeship. But that is changing. We have much more graduate students than before. In this case, the education has to be standardized to make it efficient for a larger number of the students. The training aspect is very important. In any case, I think it is important for graduate students to have curiosity, to work hard, and to grow. That is a must for their jobs, professionally.

PS: I must attest to the fact that the Japanese students are working hard. I've seen it. In the past two years, I've seen students who really put in the effort.

TK: Through my experience at Pennsylvania, it was very good that I could learn the basic physics and chemistry and basic aspects of physical chemistry, in addition to the engineering aspects in Japan. So basics are always important. Energy-related research and developments require especially broad perspectives. You need to understand many aspects of science and engineering. If you have basic knowledge, it's easy for a person to see from different aspects.

PS: You are right, for instance, if you have a solid grasp of the fundamentals, even if you go into some area that, in the end, does not hold promise for the future or gets out-passed by other competing science and technology approaches, you can reinvent yourself, right? But if you don't have the fundamentals, that's hard. I think that's a very healthy viewpoint.

TK: Too much industrialized education, which we had many years ago in Japan, was not so good. It was piecemeal training. Fundamentals are much more important.

PS: Absolutely, I agree with you. And I wish for myself that I had more fundamentals in my education. Like, for instance, quantum mechanics. I am a mechanical engineer by education, but I didn't have in-depth education on quantum mechanics, and today, there are mechanical engineering applications that involve issues related to quantum mechanics. In today's world of cross-cutting disciplines and technologies, the traditional single-discipline education is not sufficient. Again, "the all of the above approach" comes to mind.

Academic culture in Japan and advice for I²CNER

PS: Do you have any advice for our Institute? Where do you think we should focus? You have a very successful academic career, and you know the Japanese university system. Do you have any advice for me? As you know, the WPI Program aims to create environments that fuse the disciplines, and also to help reform the Japanese university system. MEXT invested in the WPI program to help universities expand and adopt an interdisciplinary approach, and see researchers adopt the fusion of disciplines approach including robust exchange and innovation.

In general, the idea is to help turn the universities into places where ideas are debated.

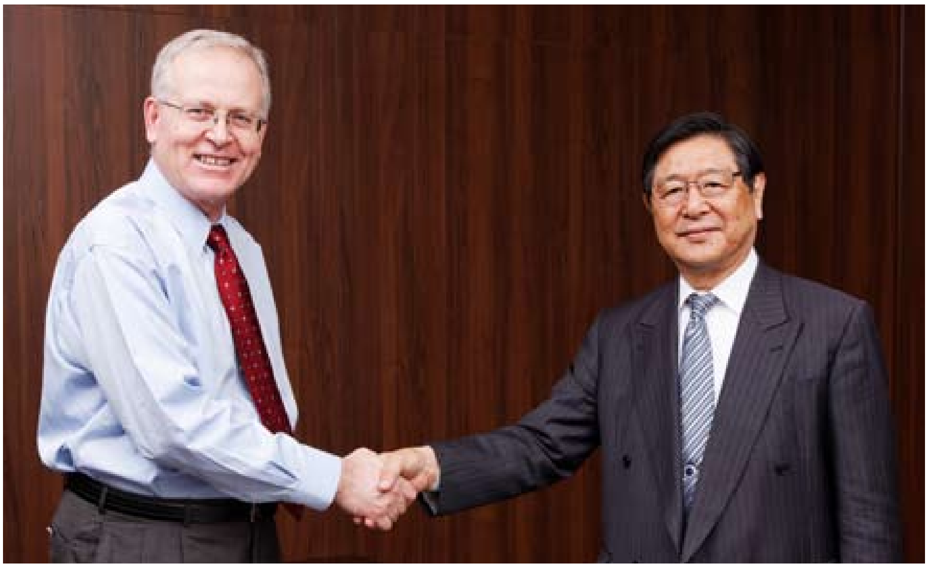
TK: When I came back from Pennsylvania almost 50 years ago to work at Kyushu University, our department was newly put together and we borrowed the graduate training system from the US system, in which professors asked students to write review papers on new topics and discuss that paper individually for one hour. I think that basic system is used in many departments here. And it is very good. The student has to think, they have to create new things, and they become well-trained in the process. That kind of flexible training is most important.

PS: I agree. This is a productive model, from the graduate student to the advisor, right? A model whereby students have the freedom to innovate, in other words.

TK: Professors sometimes are tempted to think of their graduate students as laborers.

PS: Well, it happens in the US sometimes. But it's a model, right? The student, in the end, should be a collaborator with the supervisor. And lastly, the supervisor should learn from the student. The purpose of graduate education is for the student to become better than the supervisor in his/her specific area. I thank you for the conversation. I hope in the future that I can seek your advice on such issues about the university culture, how we can interact with the university of Kyushu, and that I can ask for your wisdom if I run into a situation where I need help making a decision. It is really an honor for us to have you as a WPI Professor in our institute…I thank you for accepting our invitation.

TK: Thank you.



Dr. Petros Sofronis

1987-1990: University of California, Santa Barbara (post-doctoral)
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2010-date: Director, International Institute for Carbon-Neutral Energy Research (I²CNER), Kyushu University, Japan

Dr. Toyoki Kunitake

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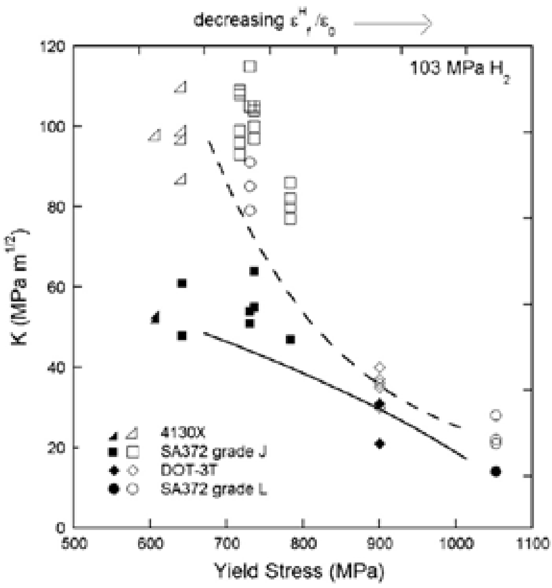
1992-1994: Dean, Faculty of Engineering, Kyushu University
1999-2008: Professor and Vice President, University of Kitakyushu
1999-2007: Group Director, Frontier Research System, RIKEN
2007-date: CTO, NanoMembrane Technologies,Ltd.
2009-date: President, Kitakyushu Foundation for Advancement of Industry, Science and Technology
2011-date: WPI Visiting Professor, International Institute for Carbon-Neutral Energy Research (I²CNER), Kyushu University

The Relationship Between Crack-Tip Strain and Subcritical Cracking Thresholds for Steels in High-Pressure Hydrogen Gas

Kevin A. Nibur, Brian P. Somerday, Chris San Marchi, James W. Foulk, Mohsen Dadfarnia and Petros Sofronis
Metall and Mat Trans A, 44, 248-269(2013) DOI: 10.1007/s11661-012-1400-5

One safety consideration for hydrogen containment systems is the well-known phenomenon of hydrogen embrittlement. Hydrogen embrittlement can accelerate fatigue crack propagation and reduce fracture toughness of structural components, which can lead to unexpected and catastrophic failures unless this material degradation phenomenon is understood and accommodated. Critical to predicting the remaining service life of containment components such as pressure vessels are accurate measurements of the hydrogen-assisted cracking resistance of steels in the service environment, i.e., up to 100 MPa hydrogen gas. In this study of pressure vessel steels in 100 MPa hydrogen gas, hydrogen-assisted cracking thresholds were measured using two different standardized methods: constant-displacement fracture mechanics tests that yield the crack-arrest threshold and rising-displacement fracture mechanics tests that yield the crack-initiation threshold. In the past, such standardized methods were thought to provide equivalent measurements of the cracking threshold. However, the data from this study demonstrate that crack-arrest thresholds are greater than crack-initiation thresholds, and this difference is magnified in steel having lower strength. The implication of these results is that employing the crack-arrest thresholds for lower-strength steels can lead to non-conservative assessments of remaining life in hydrogen pressure vessels. The mechanistic interpretation of these results is based on the local mechanics near crack tips in these low-strength steels. Essentially, the crack-tip strain field that drives hydrogen-assisted crack extension in these steels is not equivalent for the two test methods.



Crack arrest thresholds in 103 MPa H_2 gas from constantdisplacement tests (K_{THa}), open symbols, and crack initiation thresholds from rising-displacement tests (K_{THi}), filled symbols, plotted as a function of yield strength. The solid and dashed lines show general trends of Eqs. [3] and [7], respectively, as a function of $\varepsilon_f{}^H/\varepsilon_0$.

Fuel cell electrocatalyst using polybenzimidazole-modified carbon nanotubes as support materials

T. Fujigaya, N. Nakashima
Advanced Materials, 25, 1666-1681(2013) DOI: 10.1002/adma.201204461

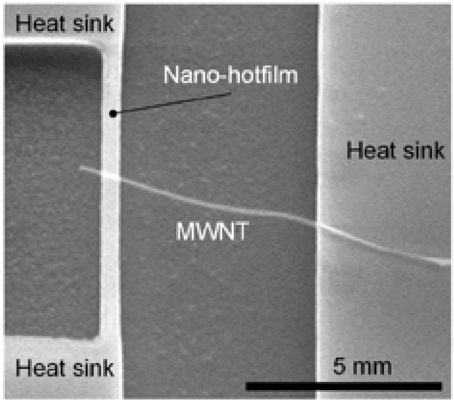
The use of carbon nanotubes (CNT) as a supporting material for PEFC electrocatalysts is ideal due to the high durability coming from the highly graphitized structure of CNTs. However, the homogeneous loading of metal nanoparticles onto the CNT surface is difficult due to the highly graphitized structure. Typically, the graphitized surface is treated by severe oxidation in order to introduce binding sites for metal nanoparticles. However, such oxidation treatments damage the graphitic structure, resulting in poor durability. Therefore, a novel idea of how to load metal nanoparticles onto undamaged CNTs was required. In this article, we reviewed our novel approach, in which polybenzimidazole (PBI) is wrapped onto untreated CNTs and acts also as a biding site for Pt nanoparticles. By this approach, CNT-based electrocatalysts were obtained without introducing any damage into the CNT structure. In addition, PBI served as a proton conductor so that the composite of CNT, PBI and Pt possesses electron conductivity, proton conductivity and a reaction site, all of which are required for PEFC electrocatalysts. Since PBI shows proton conductivity at higher temperature ~200 °C compared to conventional polyelectrolytes such as Nafion, our PBI-containing electrocatalysts are utilized in a PBI-based PEFC. PEFC operation at temperatures over 100 °C afford many benefits including i) enhancement of reaction rates, ii) high CO tolerance and iii) replacement of Pt to the other cheaper metal, all of which contribute to the reduction of the cost of PEFC systems. Furthermore, the PEFC operation at higher temperatures results in high power generation efficiency.

Figure. (TOP) Schematic diagram of platinum nanoparticles decorated on PBI-coated carbon nanotubes. (BELOW) Electron microscopy of this same CNT-PBI-Pt electrocatalyst system.

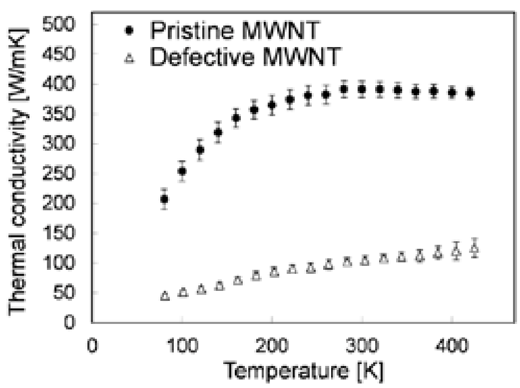
Enhanced anisotropic heat conduction in multi-walled carbon nanotubes

Hiroyuki Hayashi, Tatsuya Ikuta, Takashi Nishiyama, and Koji Takahashi
Journal of Applied Physics, 113, 014301(2013) DOI: 10.1063/1.4772612

The strong sp^2 covalent bonds and the long phonon mean free path yield high thermal conductivities in carbon nanotubes. However, the detailed mechanism of heat conduction in multi-walled carbon nanotubes (MWNTs) has been scarcely investigated, even though MWNTs can be synthesized at much lower cost than single-walled carbon nanotubes. Here, anisotropy of heat conduction in MWNTs is investigated by measuring heat flows in a pristine MWNT and in a MWNT with defects, which was thermally oxidized (490°C/60 min) under atmospheric conditions. The in- and out-of-shell thermal conductivities of each MWNT graphite shell are determined, and differences of more than four orders of magnitude are obtained because of the inter-shell gaps. This enhanced anisotropy reduces the conductance by 74% compared with that of the pristine MWNT because of the presence of outer shell defects, which comprise only 2.8% volume ratio. Furthermore, the anisotropy-assisted length dependence of thermal conductivity is demonstrated, even though there is no ballistic phonon transport.



Experimental set-up to measure the thermal conductivity of an individual MWNT using a nano hot-film

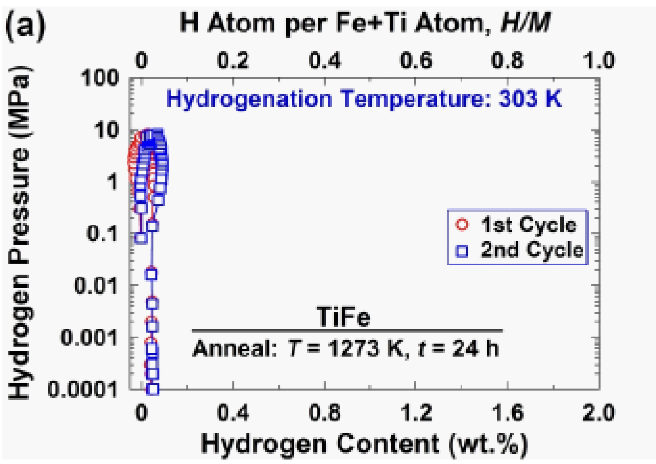


Thermal conductivities of pristine and defective MWNTs measured at different temperatures

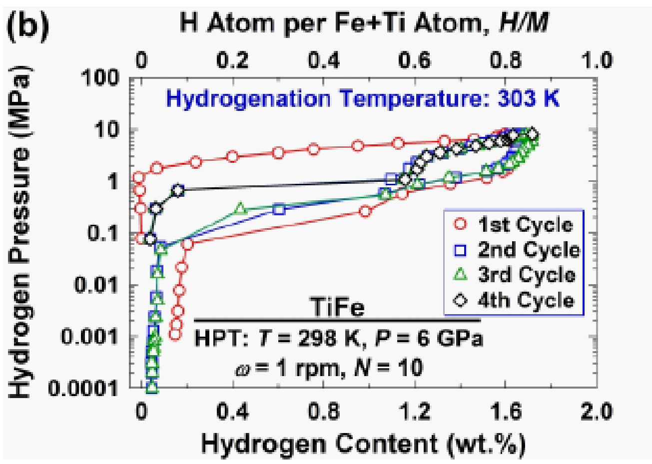
High-pressure torsion of TiFe intermetallics for activation of hydrogen storage at room temperature with heterogeneous nanostructure

Kaveh Edalati, Junko Matsuda, Hideaki Iwaoka, Shoichi Toh, Etsuo Akiba, Zenji Horita
International Journal of Hydrogen Energy, 38, 4622-4627(2013) DOI: 10.1016/j.actamat.2013.02.042

TiFe is a potential candidate for the stationary hydrogen storage systems, but it requires initial activation to absorb hydrogen. This study shows that TiFe processed by high-pressure torsion (HPT) absorbs and desorbs 1.7 wt.% hydrogen at room temperature without activation. The absorption pressure decreases from 2 MPa in the first hydrogenation cycle to 0.7 MPa in the latter cycles. The HPT-processed TiFe exhibits heterogeneous microstructures composed of nanograins, coarse-grains, amorphous-like phases and disordered phases with a high hardness of w1050 Hv.



P-C isotherms at 303 K of TiFe after annealing at 1273 K for 24 h under an Ar atmosphere

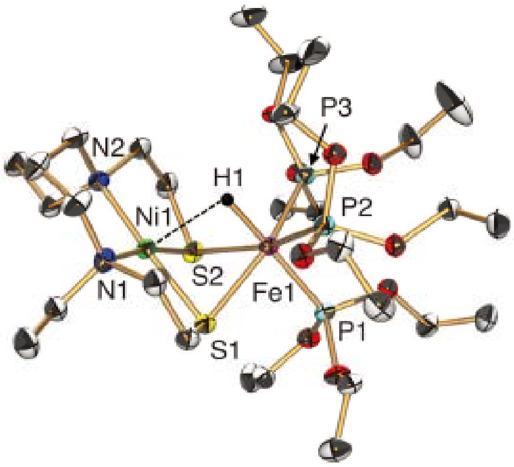


P-C isotherms at 303 K of TiFe after HPT processing for 10 turns in air

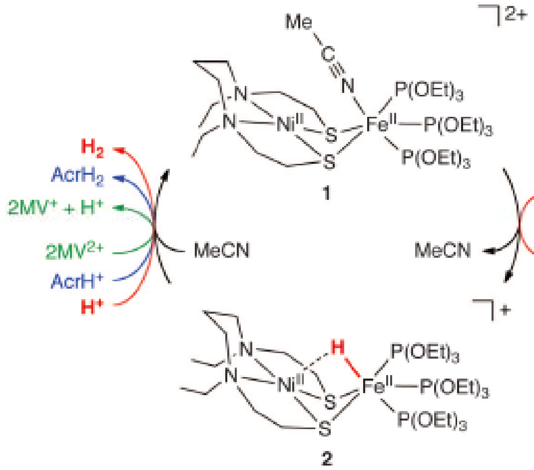
A functional [NiFe]hydrogenase mimic that catalyzes electron and hydride transfer from H_2

Ogo S., Ichikawa K., Kishima T., Matsumoto T., Nakai H., Kusaka K., Ohhara T.
Science 339, 682 (2013) DOI: 10.1126/science.1231345

Chemists have long sought to mimic enzymatic hydrogen activation with structurally simpler compounds. Here, we report a functional [NiFe]-based model of [NiFe]hydrogenase enzymes. This complex heterolytically activates hydrogen to form a hydride complex that is capable of reducing substrates by either hydride ion or electron transfer. Structural investigations were performed by a range of techniques, including x-ray diffraction and neutron scattering, resulting in crystal structures and the finding that the hydrido ligand is predominantly associated with the Fe center. The ligand's hydridic character is manifested in its reactivity with strong acid to liberate H_2.



Crystal structure of [NiFe]complex



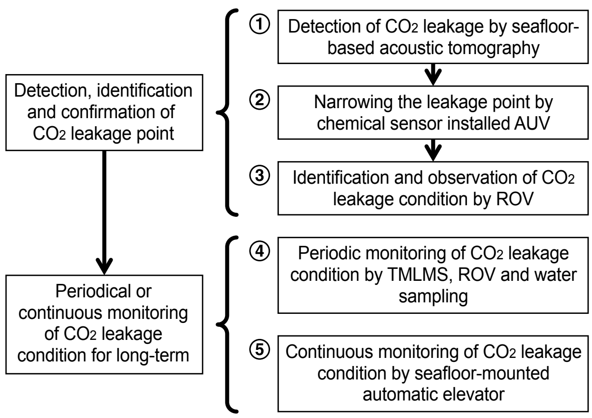
Heterolytic activation of H_2 by [NiFe]complex

Development of detection and monitoring techniques of CO_2 leakage from seafloor in sub-seabed CO_2 storage

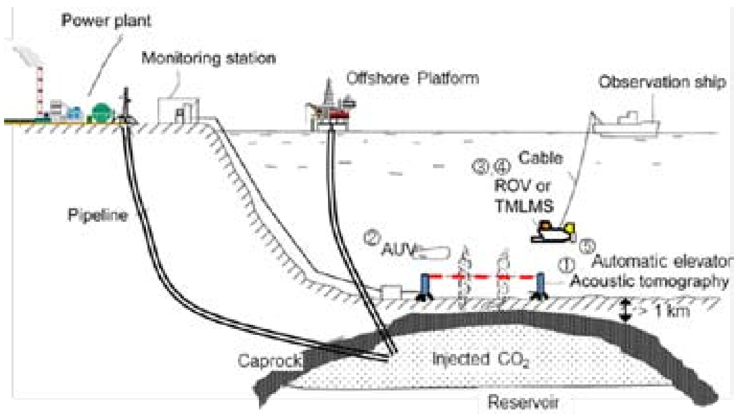
Kiminori Shitashima, Yoshiaki Maeda, Takashi Ohsumi
Applied Geochemistry, 30, 114–124 (2013) DOI: 10.1016/j.apgeochem.2012.08.001

CCS in sub-seabed geological formations is currently being studied as a potential option to mitigate the accumulation of anthropogenic CO_2 in the atmosphere. To investigate the validity of CO_2 storage in the sub-seafloor, development of techniques to detect and monitor CO_2 leaked from the seafloor is vital. Seafloor-based acoustic tomography is a technique that can be used to observe emissions of liquid CO_2 or CO_2 gas bubbles from the seafloor. In situ pH/pCO_2 sensor can take rapid and high-precision measurements in seawater, and is, therefore, able to detect pH and pCO_2 changes due to the leaked CO_2. Thus, by installing the sensor onto an AUV, an automated observation technology is realized that can detect and monitor CO_2 leakage from the seafloor. Furthermore, by towing TMLMS (containing a number of the sensors and transponders) behind the AUV, the dispersion of leaked CO_2 in a CCS area can also be observed. Finally, an automatic elevator can observe the time-series dispersion of leaked CO_2.

Hence, CO_2 leakage from the seafloor is detected and monitored as follows. Step 1: monitor CO_2 leakage by seafloor-based acoustic tomography. Step 2: conduct mapping survey of the leakage point by using the sensor installed in the AUV. Step 3: observe the impacted area by using a ROV or the automatic elevator, or by towing the TMLMS.



Process for detection and monitoring of CO_2 leakage in sub-seabed CCS



Strategy for detection and monitoring of CO_2 leakage in sub-seabed CCS

AWARDS

Helmholtz International Fellow Awards

Prof. Harry L Tuller

(Principal Investigator of Fuel Cells Research Division (Massachusetts Institute of Technology, USA))

Prof. Tuller received "Helmholtz International Fellow Awards" as outstanding senior scientists based outside Germany who have excelled in fields relevant to the Helmholtz Association.

The 30th Chemical Society of Japan (CSJ) Award

Prof. Seiji Ogo

(Lead Principal Investigator of Catalytic Materials Transformations Research Division)

Prof. Ogo was awarded "The 30th Chemical Society of Japan (CSJ) Award" for his work on "A functional hydrogenase minic that catalyzes electron and hydride transfer from H_2" by the Chemical Society of Japan (CSJ).

The Japan Institute of Metals and Materials Distinguished Achievement Award

Prof. Zenji Horita

(Principal Investigator of Hydrogen Storage Division)

Prof. Horita was awarded "The 14th Japan Institute of Metals and Materials Distinguished Achievement Award" as a significant contribution to the fundamentals and applications of technology in fields of metals and materials.

The Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology

Prof. Seiji Ogo

(Lead Principal Investigator of Catalytic Materials Transformations Research Division)

Prof. Ogo received "The Commendation for Science and Technology" for his work on "Study of small molecule activation molecules catalyst in the water" by the Minister of Education, Culture, Sports, Science and Technology.

EVENT INFORMATION

IMPRES
International Symposium on Innovative Materials for Processes in Energy Systems 2013
September 4 - 6, 2013, Fukuoka, Japan

International Symposium on Innovative Materials for Processes in Energy Systems 2013 (IMPRES2013)

Date: September 4–6, 2013

Venue: I^{2}CNER Building, Ito Campus, Kyushu University, Fukuoka, Japan

Detail: http://power.mech.kyushu-u.ac.jp/impres2013/

This international symposium welcomes participants of professionals dedicated to theories, experiments and simulations, on the development of functional materials for fuel cells, heat pumps, heat storage, sorption systems and their applied aspects. Attendees will include consulting engineers, design engineers, contractors, architects, manufacturers, researchers and academics. The IMPRES has been held in every three years and this is the third international conference after the successful completion of IMPRES2007 at Kyoto, Japan and IMPRES2010, Singapore. We hope to have stimulating and lively discussion in the city of Fukuoka.