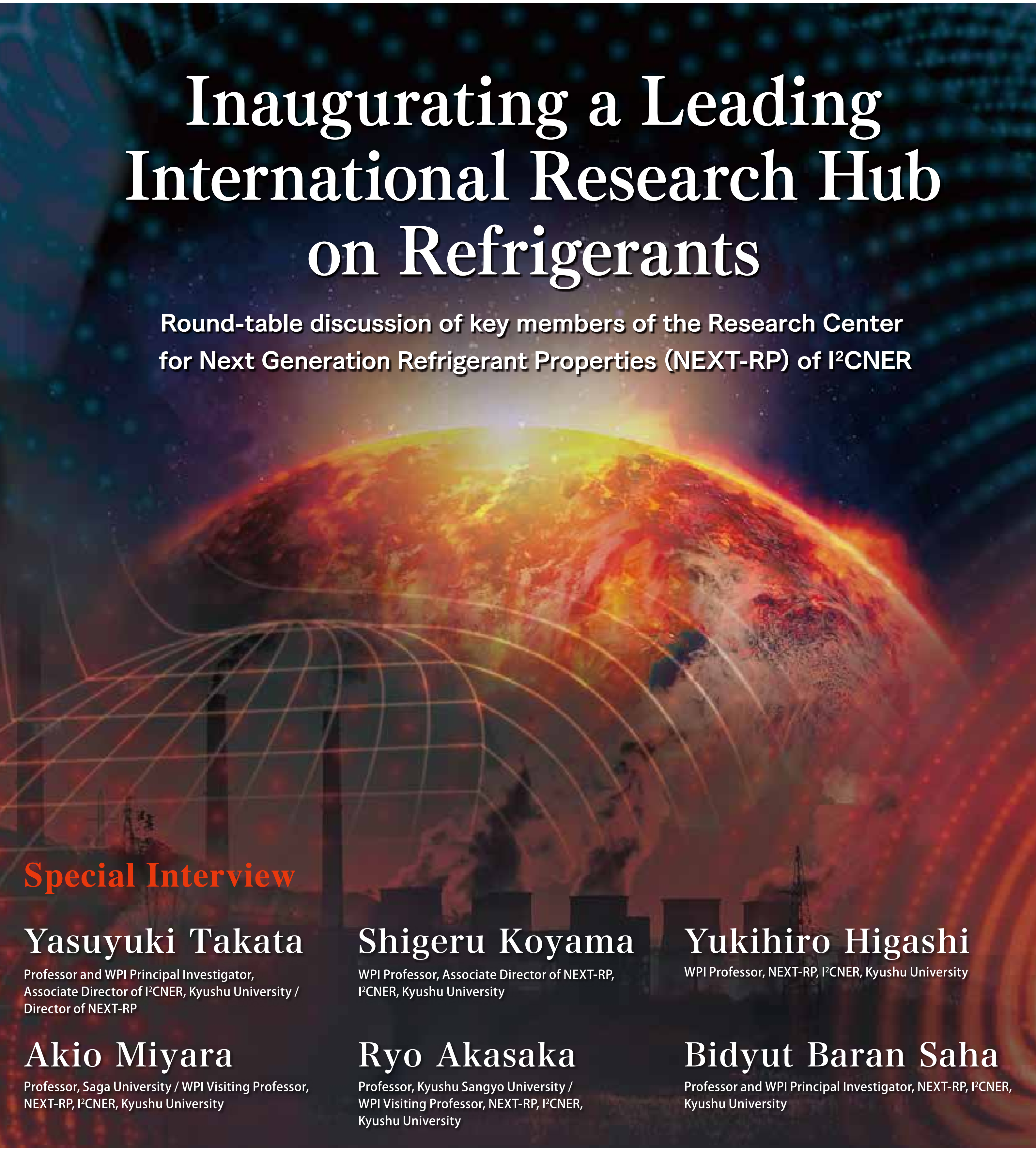
Energy Outlook

International Institute for Carbon-Neutral Energy Research

May 2017



Inaugurating a Leading International Research Hub on Refrigerants

Round-table discussion of key members of the Research Center for Next Generation Refrigerant Properties (NEXT-RP) of I²CNER

Special Interview

Yasuyuki Takata
Professor and WPI Principal Investigator, Associate Director of I²CNER, Kyushu University / Director of NEXT-RP

Shigeru Koyama
WPI Professor, Associate Director of NEXT-RP, I²CNER, Kyushu University

Yukihiro Higashi
WPI Professor, NEXT-RP, I²CNER, Kyushu University

Akio Miyara
Professor, Saga University / WPI Visiting Professor, NEXT-RP, I²CNER, Kyushu University

Ryo Akasaka
Professor, Kyushu Sangyo University / WPI Visiting Professor, NEXT-RP, I²CNER, Kyushu University

Bidyut Baran Saha
Professor and WPI Principal Investigator, NEXT-RP, I²CNER, Kyushu University

wpi World Premier International Research Center Initiative | I²CNER | KYUSHU UNIVERSITY | ILLINOIS UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Special Interview

Inaugurating a Leading International Research Hub on Refrigerants

Round-table discussion of key members of the Research Center for Next Generation Refrigerant Properties (NEXT-RP) of the International Institute for Carbon-Neutral Energy Research (I²CNER)

Though refrigerants are vitally important, both in our daily lives and various industries, most people are not very familiar with them. They are essential to all refrigeration and air conditioning. The chlorofluorocarbon (CFC) alternatives currently being used as refrigerants have a large global warming potential (GWP), which has led to concerns about their sustainability. Due to the fact that the development of sustainable, new generation refrigerants has been identified as an urgent task, the Research Center for Next Generation Refrigerant Properties (NEXT-RP) was established on April 1, 2016 as an internal organization within I²CNER. Key members of this center got together to discuss various topics, ranging from the background of the center's establishment to future perspectives.

Aiming to Create a National Hub of Research on New Refrigerants

Shigeru Koyama: Although most of my colleagues here are already familiar with it, I would like to start by briefly explaining the historical background of refrigerants. Fluorocarbon refrigerants, such as CFCs (chlorofluorocarbons) and HCFCs (hydrochlorofluorocarbons), which had historically been used as the working medium for refrigerators and heat pumps, were found to be ozone-depleting substances and were restricted by the Montreal Protocol of 1987. This led to the development of a CFC alternative, HFCs (hydrofluorocarbons). However, since HFCs have a high Global Warming Potential (GWP), they later became subject to reductions under the Kyoto Protocol of 1997. It was determined that CFCs should be globally abolished by 2010 and that HCFCs should be abolished in principle in industrialized countries by 2020. Moreover, in the case of HFCs, the international conference held in October 2016 (MOP28) mandated that industrialized countries, including Japan, should reduce production of HFCs by 85% of the 2013 level by 2036. Under these tight deadlines, we must make developing new low-GWP refrigerants a high priority. Japan has an international responsibility to lead research in this area. For all of these reasons, NEXT-RP was established in I²CNER to pursue basic research on thermophysical properties, heat exchange characteristics, and the basic recycling functions of new refrigerants that can minimize environmental impact by having both zero-ODP (zero ozone depletion potential) and low-GWP.

Yasuyuki Takata: Since I²CNER is expected to promote technology transfer, we at NEXT-RP place an emphasis on returning the results of basic research to society. To this end, we thought it was desirable to establish a research center that clearly shows our presence to the outside world, as opposed to just launching a collaborative project of several researchers.

Expectations for a Research Institute on Refrigerants Founded in Japan

Yukihiro Higashi: Although the importance of refrigerant research from the viewpoint of preventing global warming has been widely recognized, including among many in the industrial community, it is indeed basic research which is not directly linked to corporate profits. For this reason, there are clear difficulties standing in the way of continuing research. And since there is such a wide variety of users for refrigerants, it is far more straightforward to standardize regulations from a neutral academic perspective at the basic research stage. In that context, I think the significance of research that is the intellectual foundation of NEXT-RP is profound.

Akio Miyara: There are two types of expectations coming from the outside, namely, those from researchers and those from corporations. Typically, conventional approaches are taken by research groups in research institutes, where individual researchers face limitations on their achievements. However, at NEXT-RP, researchers from all over the world will be gathering to improve by cooperating and learning from each other. As such, we can expect NEXT-RP to achieve an entirely different caliber of results than those from the past. Also, I often hear from corporations at academic conferences that they expect an increase in basic research projects that lead to more applications, and that they would like NEXT-RP to conduct research in these areas.

Ryo Akasaka: Research on low-GWP refrigerants in Japan has already been at a high enough level to attract global attention. Japan is now leading the research in this field, and launching a specialized research center for refrigerants in Japan will definitely appeal to the international community. Though there have been several different approaches to refrigerant research from many different countries, the needs of the refrigeration industry have not yet been met. It is highly anticipated that NEXT-RP will propose new joint research to meet current needs, and that we will set international trends for the future.

Bidyut Baran Saha: In order to create a carbon-neutral society, improvements in energy efficiency in refrigeration and air conditioning systems are essential. The key here is a next-generation, low-GWP refrigerant. If NEXT-RP is able to make a breakthrough in refining the thermophysical properties of refrigerants, and also form a partnership with corporations to answer their needs, it will be a huge landmark in the industry. As an internal researcher at I^2CNER, I hope that NEXT-RP will promote interdisciplinary research collaborations, as well.

Future Challenges to Meet Growing Expectations

Takata: There are already several research hubs for refrigeration and air-conditioning around the world. In the United States, the University of Illinois at Urbana-Champaign, which has close ties with I^2CNER, has the Air Conditioning and Refrigeration Center (ACRC). In addition, the University of Maryland and Purdue University each have such a center. In China, Shanghai Jiao Tung University and Tsinghua University both have such research centers. What is common among these research institutions is that they receive ample funds from corporations in addition to grants from the government. In this context, it is of great significance for Japan to have a specialized research institution on refrigerants because historically, it has not had an entity that meets the needs of businesses. I believe no other national institutions have a better collection of members than NEXT-RP, which is why I have huge expectations for the center. We have two strategic challenges for the future. The first is how to strengthen partnerships with the industrial community from the viewpoint of technology transfer. The second is how to improve global recognition of NEXT-RP, which will be the only research hub for refrigerants in Japan.

Koyama: Our strategy as a Center is three-fold: first, we will explore the properties of low-GWP- and zero-ODP-based new generation refrigerants; second, we will examine the characteristic evaluations when new generation refrigerants are utilized in actual systems; and finally, we will develop proposals for optimal systems using different combinations of potential refrigerants and equipment. Crucial to achieve such difficult goals is the procurement of external funding. As Professor Takata said, in the U.S., the business community invests a considerable amount of money in the research centers at these three universities. On the other hand, since Japan has never had specialized organizations for this purpose, Japanese corporations have been forced to invest overseas. Dramatically changing this flow of research funds is another important mission for NEXT-RP. I hope we will be able to contribute to achieving the strict reduction targets specified in the Montreal Protocol by accomplishing our stated challenges and mission.

Higashi: The fact that we have a research center specializing in refrigerants that are not commonly known among the general public has great significance. As members of the Center Administration, we must not only produce outstanding research results, but also focus on ensuring the continued success of the Center. As one of our initiatives, we held a Kick-off Symposium in October 2016, where we invited prominent researchers from both Japan and abroad, with the purpose of enhancing the visibility of NEXT-RP. At the symposium, I realized how great the expectations for NEXT-RP were, and saw that both domestic and overseas industrial and academic communities have been hoping for this kind of research center to be established. We will make every effort to build a collaborative system, not only among academic researchers, but also among members of the government and business communities, in order to further develop NEXT-RP.

Miyara: For refrigerant research conducted abroad, many post-doctoral scholars and researchers come together under

Yasuyuki Takata

Professor and WPI Principal Investigator, Associate Director of I^2CNER, Kyushu University / Director of NEXT-RP

Shigeru Koyama

WPI Professor, I^2CNER, Kyushu University / Division for Heat Pump and Refrigeration Cycles, Associate Director of NEXT-RP

Yukihiro Higashi

WPI Professor, I^2CNER, Kyushu University / Division for Thermophysical Properties and Transfer Processes of Next Generation Refrigerants, NEXT-RP renowned professors and proceed with research as one unit. However, in Japan, even if innovative research is carried out in a laboratory somewhere, it lacks speed as long as it is conducted by only the one lab. Research centers abroad have often taken up the same theme as our labs, and they ultimately go on to surpass the efforts in Japan. In this sense, I expect that NEXT-RP will dramatically change the style of refrigerant research in Japan. It is expected that an inter-university network will be developed, with I²CNER of Kyushu University at the center, and that this network will cooperate with the New Energy Industrial Technology Development Organization (NEDO) and the business world to intensively promote cutting-edge research.

Akasaka: We aim to cooperate more extensively with international research organizations, the goal being to enhance the presence of NEXT-RP throughout the world. We have already held regular international workshops in collaboration with researchers from the U.S., Italy, Germany, China, and South Korea, and we also actively communicate with them to exchange new information on refrigerants. In the future, we will enter into research agreements with several institutes, including student exchange programs and seminars by invited researchers who are working on refrigerant properties. Results obtained from these collaborations will be published in papers and presented at conferences, and this will facilitate the extension of our network throughout academia and to other industries. For software development, i.e. the final step in research on properties of refrigerants, we will establish a workflow to quickly transfer our results to R&D activities in the industrial field.

Saha: More than anything else, I want to stress the importance of our international collaborative research. Currently, the U.S., England, Germany, and China are engaged in research on new refrigerants. India, Singapore, and Malaysia have also demonstrated a strong interest in this field. At NEXT-RP, it is our goal to take the lead in the research and development of low-GWP refrigerants world-wide by collaborating with researchers from these countries. The success of NEXT-RP will also give a boost to other research divisions within I²CNER.

Aiming to Be the World's Leading Research Institute on Refrigerants

Takata: Significant developments have been predicted in the refrigeration and air conditioning industry. It is expected that air conditioning equipment will prevail in developing countries, where such equipment could not be used previously due to economic considerations. In addition, global warming will make it necessary to install air conditioners in Europe, where they have not been required historically. As the reach of the industry is expected to grow, the need to reduce energy consumption and develop environmentally-friendly refrigerants is only increasing. In the U.S., the University of Illinois has the advantage with heat exchangers, Purdue University with compressor strength, and the University of Maryland with software. When NEXT-RP, which will specialize in fluids, joins this circle, various research partnerships will be accelerated. In order to promote these activities, securing sufficient funding is a crucial challenge. We need to obtain support from the industrial world as a whole, and not simply depend on the government's funding. We will solidify our research system, and then make efforts to raise researchers' awareness and nurture young researchers.

Koyama: Specifically, refrigeration and air conditioning equipment refers to refrigerators and heat pumps. There are three categories to cover, depending on the temperature level. The first one is refrigeration and the low-temperature range, where maintaining low-temperatures will be an important basic technology. The next is the temperature zone related to our living environment, ranging from normal temperatures to around the water-boiling temperature of 100°C. This zone is particularly in need of energy savings. In industry, there is great need to make use of waste heat of about 100°C released from factories and heat pumps in order to create a heat source of around 200°C. In addition to this, there is important research on a new generation medium for organic Rankine cycles, which can generate electricity from a heat source of about 200°C. With this in mind, we hope to propose innovative refrigerators and heat pump systems developed at NEXT-RP within the next five years, or ten years at the very latest. As for the training of young researchers, we consider personnel development in ASEAN countries to be an important challenge. Japanese air conditioner manufacturers have several production facilities throughout ASEAN countries, and are developing training for students and working people in those areas.

Higashi: At NEXT-RP, inter-university partnerships have been realized without a budgetary provision. This is a rare case, I think, and reflects the determination of the participating researchers, who are dedicated and passionate about our mission. In order to link this growing momentum to steady results, we must consider securing a budget as one of our most important future tasks. Since we call it a "center," it is meant to function as a hub to promote partnerships with various related organizations. While the training of next generation personnel is a priority, everyone involved is also committed to doing their utmost to make NEXT-RP the world's leading research center in the field. We kindly ask for your support and cooperation.

Akio Miyara

Professor, Saga University / WPI Visiting Professor, I²CNER, Kyushu University / Division for Thermophysical Properties and Transfer Processes of Next Generation Refrigerants, NEXT-RP

Ryo Akasaka

Professor, Kyushu Sangyo University / WPI Visiting Professor, I²CNER, Kyushu University / Division for Refrigerant Property Information and Academia-Industry Collaboration, NEXT-RP

Bidyut Baran Saha

Professor and WPI Principal Investigator, I²CNER, Kyushu University / Division for Refrigerant Property Information and Academia-Industry Collaboration, NEXT-RP

NEXT-RP Kick-off Symposium @ I²CNER

Six months after its inauguration, NEXT-RP held its kick-off symposium at I²CNER on October 7, 2016. The large crowd of participants included numerous representatives from partner organizations and businesses, including refrigerant / air conditioning manufacturers. In an effort to further promote I²CNER's broad-ranging research efforts, a lab tour for keynote speakers of the symposium was also hosted.

Lab Tour: A sample of the laboratories that were visited

Prof. Yukihiro Higashi's lab
(NEXT-RP)

Prof. Yasuyuki Takata's lab
(Thermal Science and Engineering Division)

Prof. Seiji Ogo's lab
(Catalytic Materials Transformations Division)

Prof. Masanobu Kubota's lab
(Hydrogen Materials Compatibility Division)

— Messages from NEXT-RP Kick-off Symposium Keynote Speakers —

Prof. Koichi Watanabe
Emeritus Professor, Keio University

It is unnecessary to point out that our first priority should be a concerted effort to achieve a series of productive research results in strategic areas as quickly as possible. The creative and innovative research activities that have been established in NEXT-RP could be one of the best sources of information for the global community in this area. NEXT-RP is also likely to attract attention because it is ideally positioned to be able to address the global community's ever-increasing concerns about next generation refrigerants. Emphasis should be placed on developing a systematic, targeted roadmap within NEXT-RP.

Dr. Eric W. Lemmon (REFPROP developer)
U.S. National Institute of Standards and Technology

The NEXT-RP collaboration could be very valuable in coordinating research efforts. This could take two forms: (1) By bringing researchers together to discuss their current work, new collaborations will naturally form. (2) The preparation of assessments of research completed and remaining research priorities would be very helpful — both to avoid duplication of effort and also to secure research funding. NEXT-RP should not "assign" research to different groups, but allow these coordination efforts to result naturally in more effective research.

Prof. Anthony Jacobi
University of Illinois at Urbana-Champaign

NEXT-RP has an excellent reputation from the start, owing to the established excellence and impact of the faculty involved. One idea might be to consider leveraging that reputation with a series of conferences in which you bring together a relatively small group of the most influential researchers in the area to exchange ideas. My advice would be to decide what partnerships you wish to form, being mindful that a mix of academic, corporate, and other organizations would be most powerful, then seek to identify individuals in those organizations who will champion the partnership.

1 Application to Photocatalytic H_2 Production of a Whole-Cell Reaction by Recombinant *Escherichia coli* Cells Expressing [FeFe]-Hydrogenase and Maturases Genes

Yuki Honda, Hidehisa Hagiwara, Shintaro Ida, and Tatsumi Ishihara

Angewandte Chemie - International Edition
DOI: 10.1002/anie.201600177

An inorganic photo/biocatalyst hybrid, e.g. TiO_2 + [FeFe]-hydrogenase (HydA), is of interest for an efficient H_2 production since HydA is an excellent H_2 forming biocatalyst. However, the low stability of purified HydA hampers practical applications. In this study, instead of applying purified HydA, the direct application of a whole-cell of *Escherichia coli* expressing HydA genes was applied to the hybrid system (Fig. 1). As shown in Fig. 2, the combination of TiO_2 with the whole cell formed H_2 under light irradiation, demonstrating that the whole-cell biocatalyst could be employed for the hybrid system. The new system is a promising approach for developing an efficient water splitting photocatalyst listed in I²CNER's roadmap, and contributes to realizing a clean and noble-metal-free H_2 production.

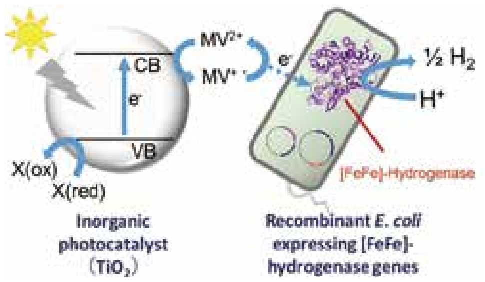


Fig. 1
Inorganic photo/biocatalyst hybrid system based on the combination of inorganic semiconductor (TiO_2), electron mediator, and the whole-cell biocatalyst.

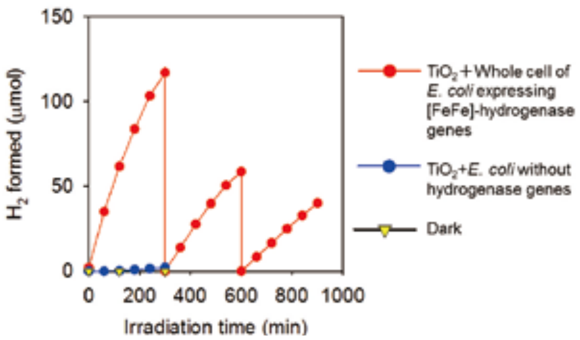


Fig. 2
Amounts of H_2 formed under light irradiation by the combination of TiO_2 and the whole-cell biocatalyst of recombinant *E. coli* expressing [FeFe]-hydrogenase genes.

2 Macroscale Superlubricity of Multilayer Polyethylenimine/Graphene Oxide Coatings in Different Gas Environments

Prabakaran Saravanan, Roman Selyanchyn, Hiroyoshi Tanaka, Durgesh Darekar, Aleksandar Staykov, Shigenori Fujikawa, Stephen M. Lyth, and Joichi Sugimura

ACS Appl. Mater. Interfaces 2016, 8, 27179–27187
DOI: 10.1021/acsami.6b06779

Despite studies showing superlubricity or ultra low friction (COF ~ 0.005) in nano and atomic scale, realizing it in macroscale (real-world applications), is always a challenge. We show that multilayer polyethylenimine/graphene oxide thin films prepared via a highly scalable layer-by-layer (LbL) deposition technique, can be used as solid lubricants (Fig. 1a). The tribological properties are investigated in air, under vacuum, in hydrogen, and in nitrogen gas environments. Fig. 1b (COF graph) shows that the superlubricity (COF <0.01) was achieved in dry N_2 with macroscale loading conditions while ambient air shows 20 times higher friction (COF ~ 0.2). Therefore, it can be assumed that superlubricity conserves the energy wasted by friction by 20 times. This superlubricity will have impact on the machines with sliding parts such as cars, trains etc., which will have a huge impact on our lives as we depend on machines for everyday life.

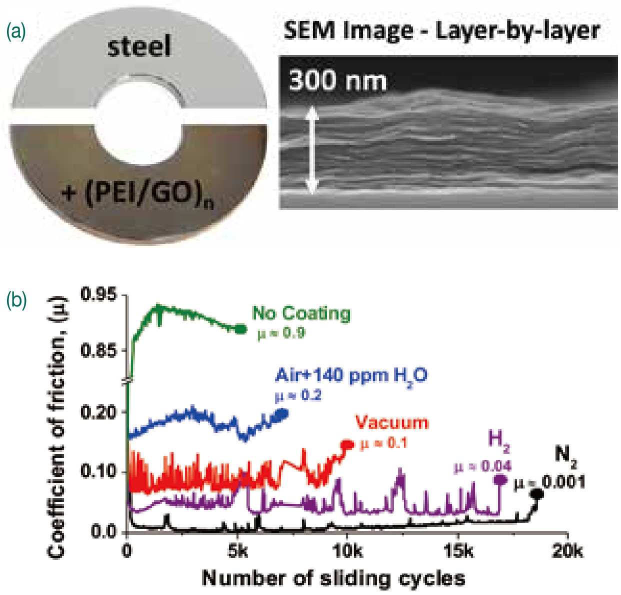


Fig. 1
(a) Digital photograph of bare steel and coated specimen (left). (a) Cross-sectional SEM image of coating on steel (right).
(b) Coefficient of friction (COF) vs Sliding number of cycles plot.

3 Determination of hydrogen compatibility for solution-treated austenitic stainless steels based on a newly-proposed nickel-equivalent equation

Setsuo Takaki, Shigenobu Nanba, Kazunari Imakawa, Arnaud Macadre, Junichiro Yamabe, Hisao Matsunaga, and Saburo Matsuoka

International Journal of Hydrogen Energy, Volume 41, Issue 33 (2016) 15095–15100
DOI: 10.1016/j.ijhydene.2016.06.193

The Hydrogen Materials Compability Division targets the development of low-cost and high-strength austenitic stainless steels with excellent resistance to hydrogen embrittlement (HE). With the current domestic regulation, the hydrogen compability of such stainless steels is determined based on a nickel-equivalent content, which is an indicater for the stability of the austenitic phase. However, the current nickel-equivalent equation does not contain nitrogen, which effectively contributes to the stability of the austenitic phase. Substituting nitrogen for nickel is an important direction to take for improving a new stainless steel with excellent resistance to HE. This study presented a newly-proposed nickel-equivalent equation, which contains nitrogen. The newly-proposed equation is expected to have the capability to contribute to the establishment of a hydrogen-based energy society, via the development of new low-cost and high-strength stainless steels with excellent resistance to HE.

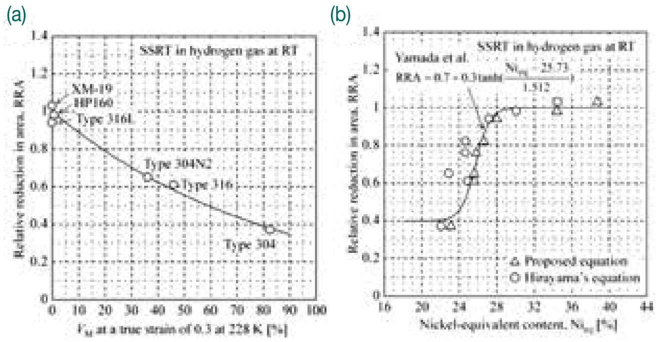


Fig. 1

Relationship among RRA, ΔV_M and Ni_{eq}: (a) RRA as a function of ΔV_M at a true strain (ε) of 0.3 and a temperature of 228 K; (b) RRA as a function of Ni_{eq} based on the proposed and Hirayama' s equations. RRA is the relative reduction in area, which is the ratio of reduction in area (RA) in hydrogen gas to RA in inert gas. ΔV_M is the net strain-induced martensite content. Ni_{eq} is the nickel-equivalent content. Fig. 1 contains the RRAs for the steels with nitrogen and the experimental result is successfully reproduced based on the newly-proposed nickel-equivalent equation.

4 Metal-Free Nitrogen-Doped Carbon Foam Electrocatalysts for the Oxygen Reduction Reaction in Acid Solution

Jianfeng Liu, Shundo Yu, Takeshi Daio, Mohammed. S. Ismail, Kazunari Sasaki, and Stephen M. Lyth

Journal of the Electrochemical Society
DOI: 10.1149/2.0631609jes

Hydrogen fuel cells could eventually replace combustion engines. However, the platinum catalyst is expensive and degrades over time, therefore Pt-free alternatives such as Fe/N/C are being investigated. Here, metal-free, nitrogen-doped carbon foam is utilized as a model electrocatalyst to investigate the role of nitrogen in the oxygen reduction reaction (ORR) in the absence of iron. Relatively high activity for the ORR in acid is obtained after graphitization, with an electron number of 3.6, revealing that a 4-electron pathway to H_2O can occur even in the absence of Fe-coordination sites. The activity is attributed to a large surface area, improved conductivity after graphitization, and the high proportion of tertiary nitrogen. This work will lead to improved design of non-precious fuel cell catalysts.

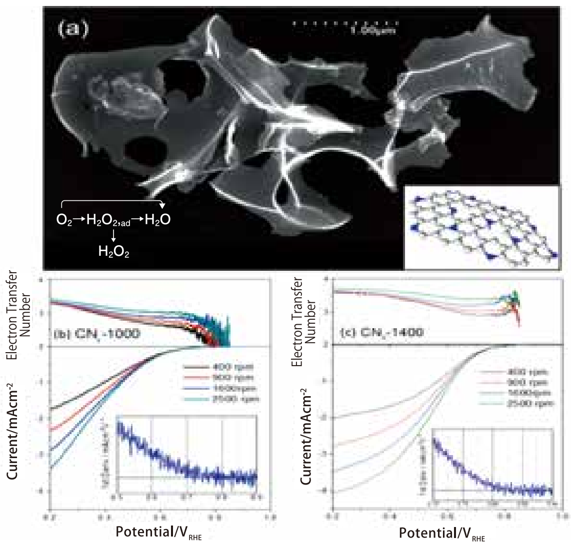


Fig. 1

(a) Scanning electron microscopy of nitrogen-doped carbon foam (CNx), showing the oxygen reduction reaction (inset left) and schematic chemical structure (inset right). Linear sweep voltammograms showing the oxygen reduction current density, electron transfer coefficient, and onset potential for CNx catalysts pyrolysed at (b) 1000˚C and (c) 1400˚C.

5 Heat Transfer through a Condensate Droplet on Hydrophobic and Nanostructured Superhydrophobic Surfaces

Shreyas Chavan, Hyeongyun Cha, Daniel Orejon, Kashif Nawaz, Nitish Singla, Yip Fun Yeung, Deokgeun Park, Dong Hoon Kang, Yujin Chang, Yasuyuki Takata, and Nenad Miljkovic

Langmuir, Vol. 32, pp.7774-7787, 2016
DOI: 10.1021/acs.langmuir.6b01903

Understanding the fundamental mechanisms governing vapor condensation on nonwetting surfaces is crucial to a wide range of energy and water applications. In this paper, we reconcile classical droplet growth modeling barriers by utilizing two-dimensional axisymmetric numerical simulations to study individual droplet heat transfer on nonwetting surfaces (90 °< θa < 170 °). It is found that the majority of heat transfer occurs at the three phase contact line, where the local heat flux can be up to 4 orders of magnitude higher than at the droplet top. We studied condensed water droplet growth using optical and environmental scanning electron microscopy on biphilic samples consisting of hydrophobic and nanostructured superhydrophobic regions, showing excellent agreement with the simulations. Our results demonstrate the importance of resolving local heat transfer effects for the fundamental understanding and high fidelity modeling of phase change heat transfer on nonwetting surfaces.

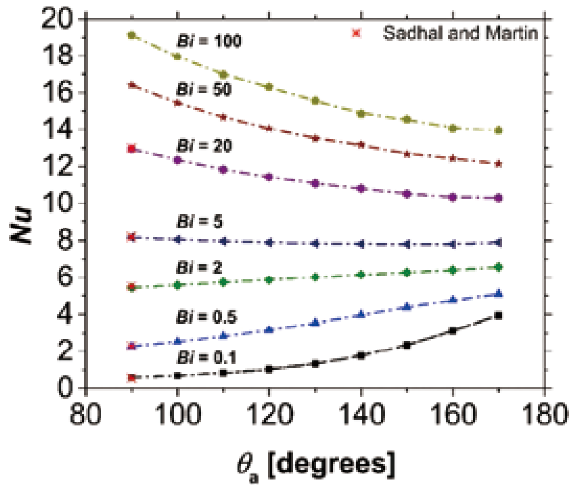


Fig. 1
Droplet Nusselt number as a function of apparent advancing contact angle for different Biot numbers.

---

6 Experimental and Quantum Chemical Approaches to Develop Highly Selective Nanocatalysts for CO_2-free Power Circulation

Miho Yamauchi, Naoki Ozawa, and Momoji Kubo

Chemical Record
DOI: 10.1002/tcr.201600047

We have proposed a new concept involving CO_2-free electric power circulation systems via highly selective electrochemical reactions of alcohol/carboxylic acid redox couples. We achieved the preparation of Fe-group nanoalloy catalysts to generate electric power from an alcohol, which is a highly storable and transportable liquid fuel, and TiO_2 catalysts which enable reproduction of an alcohol via electroreduction of a carboxylic acid, which is an oxidized waste of an alcohol. Design concepts for nanocatalysts able to catalyze highly selective electrochemical reactions are provided from both experimental and quantum mechanical perspectives. Our results are expected to greatly contribute to the effective use of renewable electricity and realization of a sustainable society, and contributes to the realization of carbon-neutral energy circulation, one of the final targets in the Catalytic Materials Transformations Division.

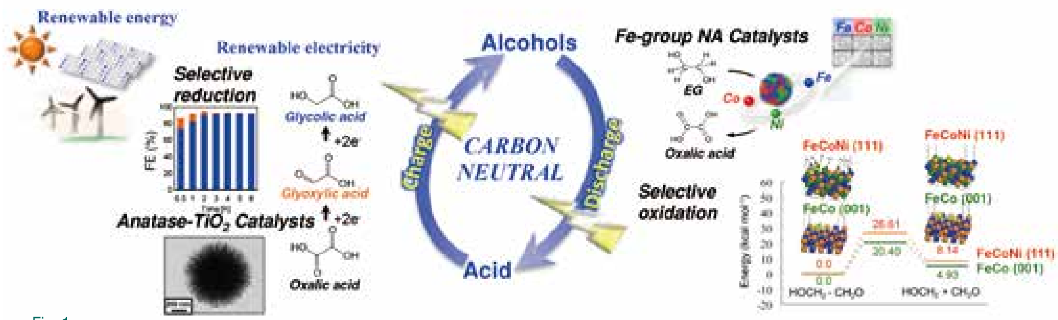


Fig. 1
Highly selective catalytic reactions of alcohols/carboxylic acid redox couples on the well-designed catalysts enable CO_2-free power circulations.