Global Aqua Innovation Center
for Improving Living Standards and Water-sustainability
Global Aqua Innovation Center for Improving Living Standards and Water-sustainability

The Center of Innovation (COI) proposal, submitted jointly by Shinshu University, Hitachi Infrastructure Systems Company, Toray Industries, Inc., Showa Denko K.K., the National Institute for Materials Science, and Nagano Prefecture, was selected by the Ministry of Education, Culture, Sports, Science and Technology and the Japan Science and Technology Agency at the end of October 2013 under their Center of Innovation Science and Technology based Radical Innovation and Entrepreneurship Program (COI STREAM). Shinshu University’s Center, one of 12 such sites in Japan, has been launched as the Global Aqua Innovation Center for Improving Living Standards and Water-sustainability.

Three Visions of COI STREAM
The model Japan should pursue in 10 years

Backcasting from society’s future needs to determine current research themes, this COI program is a program for research and development, conducted at innovation sites throughout the country for up to nine years with the aim of realizing the above three visions. As part of the proposal formulation process, Shinshu University hosted a series of dialogues under the title Future Session to identify the various needs that future societies will have to meet to ensure material comfort, including adequate supply of food and drinking water, economic prosperity, and health. The discussions made clear that achieving this goal will depend on the ability to secure and circulate adequate water supplies from diverse sources around the world, and that doing so will make a significant contribution to global sustainability.

Greeting | Kunihiro Hamada
President
Shinshu University

Shinshu University values the mountainous natural environment of Shinshu, providing education and conducting research aimed at creating a caring society. The University has long worked with local industry and the community at large on initiatives aimed at achieving these goals, and we pursue original, world-class interdisciplinary research in line with our principle of working in harmony with nature. The Center of Innovation (COI) program is an R&D program driven by a national vision of how Japan should develop over the next decade. As part of this program, the Global Aqua Innovation Center aims to ensure that people throughout the world have access to adequate supplies of clean, safe water. To this end, we are focusing on the development of innovative desalination and water reclamation systems. Marshaling research capabilities of the whole University with a particular focus on nanofiber engineering and materials science (both key strengths of the University), the Center has also brought together research institutes and private enterprises to create an all-Japan organization for researching nanofiltration (NF) and reverse osmosis (RO) membranes, and for modularizing these technologies to develop systems for real-world deployment. Given the tremendous diversity in both location and purpose of such systems, we need to tackle our mission from many different perspectives, and we greatly appreciate the cooperation and support that we receive for our efforts to achieve these goals.
We cannot live without water. And yet, the current situation is such that around 40% of people in the world are struggling with water scarcity. One of the Sustainable Development Goals (SDGs), a collection of international goals adopted at the United Nations Sustainable Development Summit of September 2015, is to “Ensure availability and sustainable management of water and sanitation for all” by 2030. In order to achieve this goal, we need more than anything to construct safe and reliable water circulation systems through the desalination of seawater and salt water, as well as the purification of contaminated water.

Through this COI, the universities, the research institutes and the industries work together to tackle these issues in a comprehensive manner, from fundamental research to applied development. By doing so, we will develop high quality and robust water-separation membranes based on Shinshu University’s outstanding nanocarbon technologies, which will enable us to construct innovative freshwater generation systems and sustainable water circulation systems.

Today, water-separation membranes produce and purify some 20 billion cubic meters of water each year worldwide, roughly equivalent to 20% of Japan’s annual water use. Population growth, advancing industrialization, and economic development are expected to drive growing water use on a global basis. To meet the needs generated by this growth, an ever-widening net has been cast to identify additional water sources: from groundwater, river water, and inland waters to sea water and consumer and industrial wastewater. Nonetheless, it is becoming ever more difficult to secure high-quality water. Many of the problems confronting water treatment plants that use separation membranes involve the fouling of separation membranes. Since fouling is inevitable when using such membranes, plants must find ways to continue operating efficiently while cleaning them, whether by chemical or other means. Key features of separation membranes required to secure high-quality water at a reasonable cost include (i) a correct balance between water permeability and separation performance at high levels and (ii) resistance to heat and chemicals. Selective separation, which is required to recover valuable materials from water, is also expected to become a major feature as we move forward. Nanocarbon technologies will be core to all these efforts, and we expect this facility to develop world-leading separation membrane technologies, module technologies, and systems technologies.

Water-related social issues touch on land management, disaster prevention, energy, food, industrial use, living environment, culture and many other areas that are all closely intertwined. As such, any approach that tackles issues separately and limits itself to the air, sea, rivers, lakes or other domain specifically related to the issue being studied can never yield a real solution. The resolution of water-related issues requires an integrated, comprehensive perspective that treats any specific issue as part of the hydrological general circulation system that consists of the movement and storage of water. In the first three-year period, this COI satellite has investigated and examined water issues across Japan and the world. In so doing, and through innovations in water-production science and technology, this project will help to ensure a century of global water abundance.

Water will be a key issue in ensuring the sustainability of the human race in the 21st century. The purpose of this project is to make abundant water available for residential, industrial, agricultural, and livestock uses through innovations in water-recycling science and technology, and to apply these innovations in the recovery of usable water from previously unappetized or underutilized sources, including sea, produced and waste water. To achieve the necessary innovations in water production, this facility will push forward with concurrent and parallel R&D efforts in areas ranging from the development of innovative and robust water-separation membranes based on nanocarbons (and equipment incorporating these membranes) to the development of water-production plant systems and technologies to simulate water circulation. The facility will promote joint research through partnerships involving industry, academia, and the public sector, assembling experts from across Japan. Shinshu University will play a central role in these efforts. In addition, by developing business models that can be deployed worldwide, this project will create new industries in communities across Japan and the world. In so doing, and through innovations in water-production science and technology, this project will help to ensure a century of global water abundance.

I would like to express my gratitude to Hitachi, Toray, and the many other companies and research institutes who have gathered under the auspices of Shinshu University’s International Center for Science and Innovation (AICS). It is exciting to see the Global Aqua Innovation Center conduct research and development on the application of Nagano Prefecture’s renowned nanocarbon technology to the development of new water separation membranes for innovative desalination and water reclamation systems aimed at resolving the world’s water problems. I have great expectations for this project also as an initiative that will drive the creation of next generation industry under Nagano Prefecture’s Land of Happiness Creation Plan (five-year basic action plan). Nagano Prefecture will continue to play an active role in promoting the early implementation of R&D outcomes of this project by sponsoring technology gatherings and other events aimed at promoting the participation of Nagano companies with outstanding technologies. I wish for the success of everyone involved in the project and fervently hope that the R&D efforts of this Center result in innovative outcomes that make a major contribution to the further development of society.
Roadblocks to securing safe, reliable water represent a serious worldwide threat. More than 1.1 billion people currently lack access to safe drinking water, while 2.6 billion live amidst inadequate environmental and water sanitation standards (including problems associated with inadequate sewage treatment). According to a report from the Organization for Economic Co-operation and Development, contaminated water kills more than 2 million children annually. Meanwhile, the World Bank reports that inadequate access to irrigation water and other related factors have led to food shortages that are affecting 925 million people around the world. The world’s population is, moreover, expected to top 8 billion by 2030, further exacerbating the water crisis. Human beings need water to survive, but most of the earth’s water, including sea water and glaciers, remains unavailable for geographic reasons or unacceptable for use due to its physical properties. Sources of readily accessible fresh water, like groundwater and river water, account for no more than 140 thousand cubic kilometers of water, or 0.01% of the earth’s total water. Today, about 70% of the world’s water supply is used for agriculture, 20% for industrial uses, and 10% for consumer use. The water used for food production thus accounts for an extraordinarily high percentage of water use. However, dramatic growth in the world’s population has resulted in persistent food shortages. A key factor behind these shortages has been a lack of access to irrigation for agriculture. Unfortunately, ever greater pressure on the food supply and rising prices appear inevitable. Since Japan relies on imports for more than 60% of its food supply, this translates as a massive dependence on water sourced overseas. Water shortages and pollution overseas can thus lead directly to problems with Japan’s food supply. In most countries and regions, tap water must meet stringent safety and quality standards, as it is used for drinking and the sustenance of daily life. Even trace levels of toxins or odors in tap water are certain to generate anxiety and complaints. But water is also used intensively for agricultural, industrial, and other purposes - in fact, about 90% of all water use is accounted for by agricultural and industrial applications. This water does not need to meet the same high standards as tap water, which points to the importance of securing the water quantity and quality appropriate for the intended application. Aimed at developing innovative desalination and water reclamation systems, the six research themes listed in the figure on the right were identified by backcasting from future needs in the light of the various water issues we face today.

### Water Resources on the Earth

**Sources of readily accessible fresh water account for a relatively small proportion of the earth’s total water.**

- **Glaciers, etc.** 1.76%
- **Fresh water** 2.53%
- **Unavailable underground water, etc.** 0.76%

Amount of the earth’s water is about 1.4 billion km³

- **Sea water** 97.47%
- **Fresh water** 2.53%
- **Unavailable underground water, etc.** 0.76%

Source: The third World Water Forum

### Water Issues on the Earth

1. More than 1.1 billion people currently lack access to safe drinking water. Inadequate access to irrigation water and other related factors have led to food shortages that are affecting more than 9 billion people

2. Uneven distribution of water: Unbalanced supply and demand

3. Importance of exploiting useful hydrosphere resources, and increasingly fierce international competition

4. Reducing the cost and energy consumption of sea water and brackish water desalination, etc.

5. Securing industrial and resource development water sources (produced water), and reusing wastewater

6. Existing man-made water circulation systems do not take natural circulation into account. Water circulation in a particular region is an open system that depends on interactions with the water circulation of surrounding regions.

### World Population Will be Above 8 Billion in 2030!

World water intake will increase by 40% and it will be increasingly difficult for us to secure water supply.

**World Water Intake**

- **1995** About 6 billion people
- **2030** About 8 billion people

Increase by 40%
Securing the Agricultural Water Needed for Food Production

The greatest challenge will be to develop desalination and material separation technologies based on robust water separation membranes composed of nanocarbons and other novel materials. If such membranes could be manufactured at low cost, they would open the way not only to 1) the widespread desalination of sea water, but also through combination with oil, particle, and heavy metal adsorption removal and other primary treatments, to 2) the treatment of produced water generated in conjunction with petroleum and other resource extraction, and 3) the desalination and purification of brackish lake and pond water and recovery of valuable resources. The desalination of sea water is already being carried out on an industrial scale in Asia, the Middle East, and other regions using reverse osmosis membranes made with petroleum derivatives. However, less expensive solutions are required to promote the use of desalinated water in agriculture, which accounts for 70% of water use. Innovative use of carbon and other novel materials to develop energy-efficient, high-performance water production systems would likely put such systems within the reach of developing countries. To this end, the technologies developed using novel materials need to be modularized and incorporated into manufacturing plants to identify and remedy any real world production system problems. This Center brings together people from universities, research institutes, private enterprise, local government, and other organizations from across Japan to create a robust organization for collaboration between academia, industry, and government to develop and deploy innovative desalination and water reclamation systems.

### R&D Challenges Derived from the Backcasting Approach

1. Affordable sea water desalination achieved through energy saving
2. Reclamation of produced water from conventional/nonconventional resources
3. Development of utilization technologies for brine or brackish water and recovery of valuable resources
4. Development of highly innovative water-related science and technology
5. Development of general water circulation models (including land use and underground water reclamation systems), computational simulation and predictions.
6. Practical implementation of “desalination and water reclamation systems” for improving living standards and water-sustainability

### Target Water Resources

1. **Sea Water**
   - Most regions suffering from water shortages are near coastlines, which means desalination is a viable solution. Polymer-based reverse osmosis (RO) membranes are the mainstay of current sea water desalination technology.

2. **Produced Water**
   - Increasing volumes of produced water (oil-contaminated water generated as a byproduct of petroleum and natural gas production) are being generated in recent years. This water needs to be treated to remove oil and salts so that it can be reused.

3. **Brine or Brackish Water**
   - Brine or brackish water, water containing salt, may provide an inland source of lithium and other useful substances in high concentrations. Such water should be desalinated to recover the useful resources.

### Key R&D Technologies for our Future Vision

- **Reverse Osmosis Membrane Element**
  - Sea water
  - Pretreatment device before desalination process
  - Desalination device
  - Concentrate
  - Permeate collection tube
  - Permeate flow
  - Permeate flow

- **Osmosis Membrane**
  - Polymer RO membrane
  - Reverse chamber
  - Pretreatment water chamber
  - High-pressure pump
  - Permeate collection tube

- **New RO Membrane Technologies for High-Concentrated Salty Water**
  - Toward the additional energy saving, cost reduction, heat resistance, high durability

- **Tailor-made carbon RO membrane technology**
  - Expected performance
    - Durability /Heat resistance
    - Chemical resistance
    - Fouling resistance
    - Sliding property
  - Based on accumulated research outcomes on carbon & nanocarbon
A Japanese Initiative from Basic Research to Real-world Implementation

The Aqua Innovation Center aims to develop innovative desalination and water reclamation systems that can be used worldwide. This will require the merging of world-class technologies possessed by Japanese companies, universities and other research organizations. The illustration on page 7 shows the roles of respective research teams and the relationship between the R&D projects being conducted simultaneously by them. Led by Shinshu University Distinguished Professor Morinobu Endo, renowned worldwide for his nanocarbon research, ① teams from Shinshu University, Toray, Showa Denko and Kitagawa Industries will focus on the development of carbon membranes. To support these efforts, ② a Shinshu University team led by Professor Takuya Hayashi will work with teams from the Research Organization for Information Science & Technology (RIST) and RIKEN to conduct modeling and simulation on carbon films at the atomic level. Led by senior researcher Mizuo Maeda, the RIKEN team is investigating interactions between membranes and the substances that cause them to clog so as to discover ways of preventing clogging in novel membranes. If carbon and other new materials can be used innovatively to develop energy-efficient, high-performance water production systems, they would open the way to the widespread desalination of seawater in developing as well as developed countries. And by combining oil and particle separation, heavy metal adsorption removal and other primary treatments, such systems could also be used to treat wastewater produced in conjunction with petroleum and other resource extraction, and to desalinate and purify brackish lake and pond water, recovering valuable resources in the process. ③ A team led by Shinshu University’s Professor Katsuya Teshima is investigating the use of various inorganic crystals to recover lithium and other valuable resources. Another team, led by Shinshu University’s Professor Mutsumi Kimura, is making use of findings in the field of functional polymer chemistry to develop processes for forming membranes for the separation of valuable substances, and also exploring the potential of an alternative to carbon membranes in the form of robust, plant-derived cellulose separation membranes.

Applying such core technologies once they have been developed will require their modularization and incorporation into pilot plants to iron out any system-related problems. ② Toray and ③ Hitachi will undertake this aspect of the project. ④ Shinshu University Distinguished Professor Toru Noguchi, renowned for creating the world’s strongest materials such as rubber and plastics reinforced with carbon nanotubes, will put his experience to work in developing robust materials for the above systems. COI satellite ⑤ Japan Agency for Marine-Earth Science and Technology (JAMSTEC) also has a research team working on the development of the world’s first general circulation model specifically for water reclamation so as to ensure that man-made desalination and water reclamation systems can be incorporated into natural large-scale water cycles without causing problems. This COI has accordingly brought together people from universities, research institutes, private enterprise, local government and other organizations to create a robust nationwide organization for collaboration between academia, industry and government on all aspects from the development of core technologies to real-world deployment to bring about the implementation of innovative desalination and water reclamation systems in society.
Research & Development of RO Membranes Composed of Nanocarbons (Morinobu ENDO (Shinshu University); Toray Industries, Inc. Showa Denko K.K.; Kitsugawa Industries Co., Ltd.)

Many problems that current polymer membranes and water treatment plants face involve large consumption of energy for high-pressure pumps and damage due to high-temperature of sea water. Our team aims to develop a high-performance and robust carbon separation membrane and adapt it to any condition of water source and purpose.

Research & Development of Nanocarbon RO Membrane Modules (Toray Industries, Inc.)

Toray aims to develop module production technology which can be used in desalination plant and treatment of produced water. The module has to be adapted to various water sources and consist of a heat-and-chemical-resistant nanocarbon membrane and support layer.

Systematizing Water Treatment by Using Nanocarbon RO Membranes (Hitachi, Ltd.; Kurita Water Industries Ltd.)

In cooperation with other R&D teams, Hitachi plans to make practical applications of robust nanocarbon membranes and to apply many efficient processes for various water sources. Hitachi is also studying how to achieve energy-saving targets and to get a solution for social implementation.

Peripheral and Related Technologies (Katsuya TESHIMA, Mutsumi KIMURA (Shinshu Univ.): Toclas Corporation)

This group aims to develop the process of lithium recovery from brine through the use of an ion exchange material, and to develop a water treatment membrane using nanoscale-control polymers derived from renewable biomass sources.

Water-related Science and Technology (Takuya HAYASHI (Shinshu University): RIKEN, RIST)

This team aims to develop molecular dynamics models to clarify the interaction between membrane and atoms or molecules and to help R&D teams produce nanocarbon RO membranes, clarifying the underlying phenomena of water molecules passing through the membrane.

Comprehensive Analysis and Prediction of Global Water Circulation (COI Satellite) (Keiko TAKAHASHI (JAMSTEC): Chuo Univ.)

COI Satellite aims to develop global water circulation models (ocean, atmosphere and land including underground), computational simulation and predictions to forecast the impact of our innovative water desalination and reclamation systems on the global environment.

Takuya
Hayashi
Professor, Institute of Engineering, Shinshu University (Atomic structure analysis)

Designing More Efficient Membranes through Elucidating Mechanisms

I have made it my mission to contribute to the development of carbon membranes with high separation and purification capabilities through advancing our theoretical understanding of the interactions occurring at the atomic or molecular level in carbon membranes developed for water purification, and elucidating the mechanisms behind the transport of water molecules. Specifically, we develop models of the structure of water separation membranes based on estimates of pore shapes, membrane thickness, density and other data obtained from electronic microscopy and other methods. We then get the Research Organization for Information Science and Technology or RIKEN to run simulations of atom/molecule transport, and compare the detailed data generated from these simulations with that from experiments using prototype carbon membranes. I feel that the results we have obtained so far indicate promising possibilities for these efforts deliver information regarding pore size or functional group presence and type that proves useful to the design of a more efficient membrane. There is still much that we do not know about the mechanisms whereby water molecules, which may be larger than some pores when hydrated, permeate separation membranes. I have high hopes that we will also make some interesting discoveries from the perspective of water science.

Katsuya
Teshima
Director, Center for Energy and Environmental Science, Professor, Institute of Engineering, Shinshu University (Adsorption & ion exchange membranes)

Enabling Resource Recovery Using High Efficiency, High-precision Crystalline Materials and Membranes

My mission in this project is to lay the path to lithium recovery through the use of an ion exchange material made from inorganic ceramic material. Conventional ion exchange resins are too expensive to become widely used in developing countries. For this reason, we have worked with manufacturers to develop water purifiers made of ceramic and other cheap inorganic crystalline materials that can remove heavy metals from water. The development of high efficiency, high-precision material separation membranes would also enable the separation at low cost of lithium and other elements, such as sodium, magnesium, potassium, and calcium. Lithium is present in high concentrations in brine, and is conventionally recovered by evaporation or precipitation using additives, but with the declining number of water sources suited to drying, the cost of such methods is expected to rise. I hope to contribute to Japan’s mineral strategy as an island nation by developing devices for incorporating into large-scale sea water desalination plants to recover lithium and other useful metals contained in trace quantities in sea water.

Kenji
Takeuchi
Associate Professor, Institute of Engineering, Shinshu University (Nano carbon membrane)

Towards the development of innovative water-treatment membranes which use advanced nanocarbons

My mission is to use nanocarbons to develop low-cost, tough and innovative water-treatment membranes by precisely controlling their membrane structures in a precise manner. Global water resources are becoming increasingly scarce due to such factors as recent economic growth and population growth in developing nations, as well as climate change, and water treatment is one of the Sustainable Development Goals (SDGs) set out by the United Nations with the aim of achieving global sustainability by 2030. In the 21st century, which has been called the “century of water”, there is a pressing need for a range of innovations in water-treatment membranes. Current polymer membranes such as aromatic polyamides (PA) have made great contributions in the field of water treatment, such as for reverse osmosis (RO) for seawater desalination, but while these membranes have high desalination properties, they have problems in terms of chemical resistance and contamination resistance. In this COI project, we are seeking to develop membrane innovations through membrane structures comprising of independent advanced nanocarbons or compounds of these with PA, such as carbon nanotubes or graphene, working hard to “achieve water-based societies in which anyone in the world has access to safe and drinking water at any time.”

Mutsumi
Kimura
Professor, Division of Chemistry and Materials Course, Institute of Textile Science and Technology, Shinshu University (Sub-nano porous membranes)

Mimicking the Cellulose Membranes of Mangrove Roots

My mission is to precisely control membrane pore diameter to create a separation membrane that allows water to permeate while blocking salt. Sub-tolerant plants such as mangroves use cellulose membranes in their roots to desalinate sea water and also remove viruses, with the purified water then being transported upwards through vascular cells known as tracheids. I am looking at ways of mimicking this mechanism. Cellulose is easily manufactured through photosynthesis, but is difficult to break down. However, we have found ways of dissolving cellulose in ionic liquids and then molding it into various forms. We have also succeeded in making water-permeable, size-selective parylene membranes through forming films from organic compounds designed on a substrate. Reducing porosity by reducing particle size enables the creation of sub-nano porous membranes that do not allow the passage of nano-sized sodium ions, and are thus capable of desalinating water. Looking ahead, I would also like to tackle the hurdle of osmotic pressure and create a membrane capable of desalinating sea water at about half the conventional pressure. This would considerably reduce desalination-related electricity costs.
Our COI satellite’s mission is to leverage cutting-edge information technology to drive innovation in water-related systems for society in collaboration with Shinshu University’s core institution. To achieve this mission, we are seeking to facilitate the real-world deployment of desalination and water reclamation systems by developing integrated analysis, prediction and simulation technologies for building sustainable water circulation environment systems that serve both the natural environment and humanity.

We are developing the world’s first general circulation model specifically for water in nature to serve in the real-world deployment of water systems that allow human activity to flourish while also protecting the global environment. We will use this model to run integrated simulations that incorporate artificial desalination and water reclamation systems within large-scale natural water cycles without adverse impacts. This simulation technology and our findings will be used to propose systems for using water in ways that serve both nature and humanity. We aim to present indicators of effective water use and form from so far little-discussed perspectives such as energy efficiency, ecosystem preservation, everyday life and culture in relation to water, and offer a vision of coexistence with water that incorporates the perspectives of sustainability of the natural environment and cultural continuity.

**Predicting the Behavior of Large-Scale Water Cycles of Atmosphere, Oceans, and Land**

We hope that our results will provide basis to water systems that treat the relationship between water and people as a total system and make the most of the local characteristics and potential of regions throughout the world. Hopefully this will enable the provision of a scientific basis for a vision of society within a water system framework, and lead to the emergence of unique, world-first technologies that can contribute to global business growth.

**A Sustainable Water-human Environment**

As an integral part of nature, water is inevitably affected by the global environment. We view water as a large-scale circulation system, and advocate inclusion of the water that we use in our everyday lives as part of the whole natural water system. From the perspective of the global environment and this water system positioned within nature, the desalination and water reclamation systems that this project aims to create will hopefully take the form of total systems that can be incorporated without adverse effects into the present and future natural environment, will be resilient to changes in the global environment, can be deployed with minimum energy and cost, and will also take social and cultural factors into consideration.

The earth’s water circulates between the atmosphere, oceans and land, linking them together and changing along with the global environment. Human society and water are very closely related, and historically, coexisting with water has always been a major challenge. Natural disasters of course remind us of both the importance and dangers of water, but as Japan is a country with plentiful water resources, we perhaps need to adopt a new perspective that views water as a valuable asset with the potential for exploiting in applications that reduce energy consumption and costs, and use this perspective to probe new possibilities. Such a perspective would enable Japan to take advantage of its experience in exploiting and coexisting with water to offer new pointers on water to countries and regions affected by environmental change, and would also lead to new business opportunities.

**COI-S Research Leader**

Keiko Takahashi
Director General, Center for Earth Information Science and Technology
Japan Agency for Marine-Earth Science and Technology (JAMSTEC)

The book’s water circulates between the atmosphere, oceans and land, linking them together and changing along with the global environment. Human society and water are very closely related, and historically, coexisting with water has always been a major challenge. Natural disasters of course remind us of both the importance and dangers of water, but as Japan is a country with plentiful water resources, we perhaps need to adopt a new perspective that views water as a valuable asset with the potential for exploiting in applications that reduce energy consumption and costs, and use this perspective to probe new possibilities. Such a perspective would enable Japan to take advantage of its experience in exploiting and coexisting with water to offer new pointers on water to countries and regions affected by environmental change, and would also lead to new business opportunities.

**Main Members of COI-S**

Mikiko Ishikawa
Professor, Integrated Science and Engineering for Sustainable Society, Faculty of Science and Engineering, Chuo University

Ryo Onishi
Group Leader, Center for Earth Information Science and Technology
Japan Agency for Marine-Earth Science and Technology (JAMSTEC)

Shinji Hara
Institute Professor, Research and Development Initiative, Chuo University

Toru Sugiyama
Research Scientist, Center for Earth Information Science and Technology
Japan Agency for Marine-Earth Science and Technology (JAMSTEC)
The Global Aqua Innovation Center is focusing over the nine-year span of this project on all aspects from basic research to applied research, development research and preparations for real-world deployment.

Phase 1 (FY 2013- FY 2015) was devoted to identifying the requirements for separation membranes and modularization to enable the use of seawater, brackish water, and produced water, and examination of the core technologies involved. In Phase 2 (FY 2016- FY 2018), we will test separation performance in various fields of application to confirm the advantages of carbon membranes. We will also be looking at overall modularization and system building at the practical implementation level. In Phase 3 (FY 2019- FY 2021), we will confirm performance in various application fields, and work on optimizing entire systems with the aim of preparing for real-world deployment of innovative desalination and water reclamation systems from FY 2022.

R&D Focus Areas

Phase 1 2013~
- Identification of social needs and continued backcasting
- Separation membrane and modularization technologies
- Permeate and concentrate cleanliness and systematization technologies
- Water-related science and technology
- Water environment measurement technologies

Phase 2 2016~
- Identification of various applications and module development
- Demonstration of given separation performance in various fields and confirmation of carbon membrane superiority
- Development of practical application-level operation and optimization of peripheral and systematization technologies

Phase 3 2019~
- Demonstration of performance using real produced water, brine and seawater
- Plant design, feedback to other technologies, integration of basic technologies, overall system optimization
- Analysis from the perspective of actual plant operation, improvement recommendations, application and standardization of water environment assessment indices

Practical implementation of innovative desalination and water reclamation systems, and overseas deployment

We have created a diorama that offers a three-dimensional representation of our vision for the future. This is currently on general display at the International Center for Science and Innovation (AICS). It presents a scenario in which a location that was formerly desert has been equipped with plants for desalination, produced water treatment, brackish water treatment and water reclamation, enabling the building of an industrial zone with high-rises and other facilities, a resort zone, and residential areas. During events, a model Shinano Railway train travels through the diorama, with a tiny camera mounted in the front carriage filming the view for real-time display on a TV monitor.
Main Achievements in Research and Development generated from Shinshu University COI


Success in Developing High-performance, Multifunctional Reverse Osmosis Membrane Using Nano Composite Membrane Made from Carbon Nanotube and Polyamide, Which Has Paved the Way for an Innovative Desalination System That Will Contribute to Sustainability On a Global Scale

Carbon nanotube (CNT) entanglement technology developed at Shinshu University was combined with conventional thin-film formation technology to devise a new nanocomposite film formation technology that was then used to develop an RO membrane with a polyamide composite membrane made up of highly concentrated and entangled multiwalled (MW) CNT. This had previously proved impossible to achieve by more conventional methods. The MWCTN-PA nanocomposite membrane shows not only improved water permeability, but also outstanding antifouling and chlorine resistance. The results of this research have been published in Nature’s Scientific Reports online journal.


Development of a Primary Treatment Method for Produced Water Using Exfoliated Graphite (EG) – Towards an Environmentally friendly Method of Resource Exploitation

The treatment of produced water, a byproduct of oil and natural gas extraction, has become a focus of worldwide attention in recent years from the perspective of environmental protection. In this study, oil content from model produced water (model water created from engine oil and distilled water) was selectively absorbed using exfoliated graphite (EG) obtained from natural graphite. The EG was found to reduce oil content from 100 ppm to just 0.1 ppm. The results of this research will hopefully be put to practical use as a produced water primary treatment process, with the resulting low oil content water being subjected to advanced treatment using RO or other kinds of membrane, thereby helping to mitigate the environmental impacts of natural resource exploitation. The results of this research have been published in the journal of Water Process Engineering (Elsevier).


Discovery of Process for Tough Cellulose Hydrogel Materials That Can Be Used As a Component of Water Treatment Breaking Away from the Dependence on Petroleum

This study showed that cellulose can be processed without relying on chemical treatments involving oil, acids or alkalis into very robust cellulose materials that can be molded into various forms. Researchers also succeeded in fabricating hollow fiber membranes capable of separating water from contaminants. These materials can hopefully be applied to the development of eco-friendly water treatment equipment that does not use petroleum-derived materials. The results of this research have been published in Nature’s Scientific Reports online journal.

Press Release No.4,  November 17, 2015

Molecular Dynamics Study of Carbon Nanotubes/Polyamide Reverse Osmosis Membranes: Polymerization, Structure, and Hydration – Research on the Molecular Dynamics of CNT – Polyamide Composite RO Membranes Leveraging Shinshu University’s Supercomputer to Drive Advances in Innovative RO Membrane Science

Shinshu University’s first supercomputer also played a part in producing results from research conducted under the COI project. It was used to simulate the molecular dynamics of novel composite membranes composed of polyamides (PA) to which carbon nanotubes (CNT) had been added. The results of these simulations were found to match those of experiments conducted simultaneously, showing, for example, that the smaller pore size of these membranes prevents the passage of sodium and chloride ions. The results of this research have been published in American Chemical Society (ACS)’s Applied Materials & Interfaces.
Successful Dry Process-based Synthesis of Nanostructure Controlled Carbon Water Separation Membranes Showing Outstanding Desalination Properties - Separation Capabilities Improved with Nitrogen Doping

Using a novel dry process-based membrane formation technique, researchers have developed novel carbon-based water separation membranes that are more flexible than conventional diamond-like carbon (DLC) membranes, and also show outstanding desalination performance of up to 96%. Researchers found that salt rejection, water permeability and chlorine resistance could be optimized by adjusting the amount of nitrogen added. Computer simulations also confirmed the efficacy of the membranes, which are expected to be put to practical use in resource development and other water treatment applications subject to severe conditions. The results of this research have been published in Nature’s NPG Asia Materials.

Successful Development and Improved Performance of a Graphene Oxide / Graphene Laminar Structure Membrane – A Major Step towards Practical Application through a Simple Production Method with the Capability to Increase the Area Size

We successfully prepared a laminar nano structure by creating a compound of graphene and graphene oxide to apply it as a nanocarbon membrane with an effective water treatment functionality. In addition to making it easier to increase the area size by employing a simple fabrication method by spraying a liquid mixture of graphene and graphene oxide on the substrate, we also discovered that it combines advanced salt and pigment removal properties with a level of robustness characteristic of nanocarbon materials. The results of this research were published in “Nature Nanotechnology.”

Clarification of the Fouling Resistance Mechanisms of a Multi Walled Carbon Nanotube / Polyamide Composite RO Membrane – Helping to reduce the Costs of Seawater Desalination Systems

We clarified the mechanisms that make it difficult for organic contaminants, such as proteins, to adhere to a recently developed multi walled carbon nanotube (MWCNT) – polyamide (PA) nano-composite RO membrane – in other words, the mechanisms behind its outstanding fouling resistance. During this study, we used both experimental and theoretical results based on filtration tests and molecular dynamics, respectively. These findings will allow us to reduce the operation cost of seawater desalination systems, as it inhibits the deterioration of permeability in seawater desalination systems, and greatly reduces the need for maintenance, such as the washing or replacement of membranes. The results of this research were published in the American Chemical Society journal “ACS Applied Materials & Interfaces.”

Development of a Multi Walled Carbon Nanotube / Polyamide Composite RO Membrane equipped with Scaling Resistance – Expectations for Low Cost and Environmentally Friendly Fresh Water Generation

Following on from our examination of the characteristics that make it difficult for organic substances to adhere to the MWCNT-PA nano-composite RO membrane, we also clarified the mechanisms of the high scaling resistance of the recently developed multi walled carbon nanotube (MWCNT) – polyamide (PA) nano-composite RO membrane. We found that calcium carbonate (CaCO$_3$), which causes membrane scaling, has low adhesion to the MWCNT-PA nano-composite RO membrane. In addition, this membrane also possesses an outstanding function of CaCO$_3$ self-cleaning through the flow of water, resulting in spontaneous recovery of the permeability. We believe these findings will reduce work such as membrane maintenance, and replacement, and help to avoid water feed pretreatment, resulting in a low-cost and environmentally friendly systems. The results of this research were published in the American chemistry journal “ACS OMEGA.”
The Global Aqua Innovation Center was created to conduct research and development in the field of innovative water production and circulation systems, involving itself in all stages up to practical implementation in society. The International Center for Science and Innovation was established in Shinshu University’s Nagano (engineering) campus as the project’s core facility. Researchers from Shinshu University and other universities and research institutes as well as private sector engineers are stationed at the Center to work under one roof on the development of durable water separation membranes and other applications that leverage revolutionary materials such as nanocarbons, and to explore component modularization and systemization, production plant design, commercialization and other aspects of real-world deployment. RIKEN is also participating as an independent satellite, and JAMSTEC as a COI satellite.

**Access**

**By Nagano Dentetsu Bus**
From the east exit of JR Nagano station, go to Nagano Dentetsu bus stop No.21 and take the Nisseki Line. (The journey should take about 5 mins.) Get off at "Shindai Kogakubu" and walk about two minutes.

**By Alpico Bus**
From the Zenkai exit of JR Nagano Station, go to Alpico bus stop No.2 and take one of the following: 1. For Otosukaminami via Nisseki; 2. For Matsueka; or 3. For Big Hat. The journey should take 8 mins. Get off at “Shindai kaogakubu mae” and walk three minutes.

**On foot**
Go out the Eastern Exit at JR Nagano Station. Walk for 20 minutes to campus.