Science and Technology Trends —Quarterly Review
No. 32 July 2009
Science & Technology Foresight Center of NISTEP

2009 July No.32

ISSN 1349-3671

Science & Technology Trends

Quarterly Review

Science & Technology Foresight Center, NISTEP

Life Sciences

Trends and Challenges in iPS Cell Research

Environmental Sciences

Recycling Conducted by Material Industries: Current Conditions and Hindering Factors

World Research Trends in Child Health and Environment

Nanotechnology and Materials

Trends in Research and Development of Nanoporous Ceramic Separation Membranes - Saving Energy by Applying the Technology to the Chemical Synthesis Process -

Energy

Energy Saving Lighting Efficiency Technologies

Social Infrastructure

Trends of Technology for Observing and Forecasting Localized Rains

Current Status and Future Issues of Volcanic Eruption Prediction Research

The Role of Operations Research to wards Advanced Logistics

Foreword

This is the latest issue of "Science and Technology Trends __ Quarterly Review".

National Institute of Science and Technology Policy (NISTEP) established Science and Technology Foresight Center (STFC) in January 2001 to deepen analysis with inputting state-of-the-art science and technology trends. The mission of the center is to support national science and technology policy by providing policy makers with timely and comprehensive knowledge of important science and technology in Japan and in the world.

STFC has conducted regular surveys with support of around 2000 experts in the industrial, academic and public sectors who provide us with their information and opinions through STFC's expert network system. STFC has been publishing "Science and Technology Trends" (Japanese version) every month since April 2001. The first part of this monthly report introduces the latest topics in life science, ICT, environment, nanotechnology, materials science etc. that are collected through the expert network. The second part carries insight analysis by STFC researchers, which covers not only technological trends in specific areas but also other issues including government R&D budget and foreign countries' S&T policy. STFC also conducts foresight surveys periodically.

This quarterly review is the English version of insight analysis derived from recent three issues of "Science and Technology Trends" written in Japanese, and will be published every three month in principle. You can also see them on the NISTEP website.

We hope this could be useful to you and appreciate your comments and advices.

Dr. Kumi OKUWADA
Director, Science and Technology Foresight Center
National Institute of Science and Technology Policy

NISTEP has moved to a new office

Contact information

Science and Technology Foresight Center
National Institute of Science and Technology Policy
Ministry of Education, Culture Sports, Science and Technology (MEXT)

3-2-2, Kasumigaseki, Chiyoda-ku, Tokyo 100-0013, Japan
Telephone +81-3-3581-0605 Facsimile +81-3-3503-3996
URL http://www.nistep.go.jp/index-e.html
E-mail stfc@nistep.go.jp

Executive Summary

Life Science

1 Trends and Challenges in iPS Cell Research

p.11

In August 2006, Professor Shinya Yamanaka of Kyoto University succeeded in generating cells with pluripotent differentiation capability by inserting four different genes into differentiated adult cells in mice, and he named these cells "induced pluripotent stem cells" (iPS cells). As well as proving that stem cells with differentiation potential could be generated from already differentiated cells, this new phenomenon was a great discovery in the field of Biology, showing that the differentiation process of a cell was reversible and not one way as previously believed.

In November 2007, one year after the discovery of iPS cells in mice, Prof. Yamanaka demonstrated that iPS cells could, in fact, be achieved with human cells as well. The potential that iPS cells can be generated with appropriate cell types whenever necessary brings a great hope for its applications in cell therapy, such as regenerative medicine, as well as in screening candidate drugs using human cells in the pharmaceutical industry. In addition, treatments with iPS cells may cure diseases previously regarded difficult to cure. On the other hand, much effort is still required to establish the differentiation induction methods, accumulation of information about stability and safety, foundation of a method to secure the safety, and foundation of intellectual property for industrial diffusion for their application.
"iPS cells" are a new concept in science, discovered only two years ago in Japan. The simple generation methods and their pluripotency give us hope for great innovation and medical benefits. With their possible future impact in mind, here I discuss what iPS cells will contribute and how they may change our society as well as the challenges we have to overcome to achieve them.

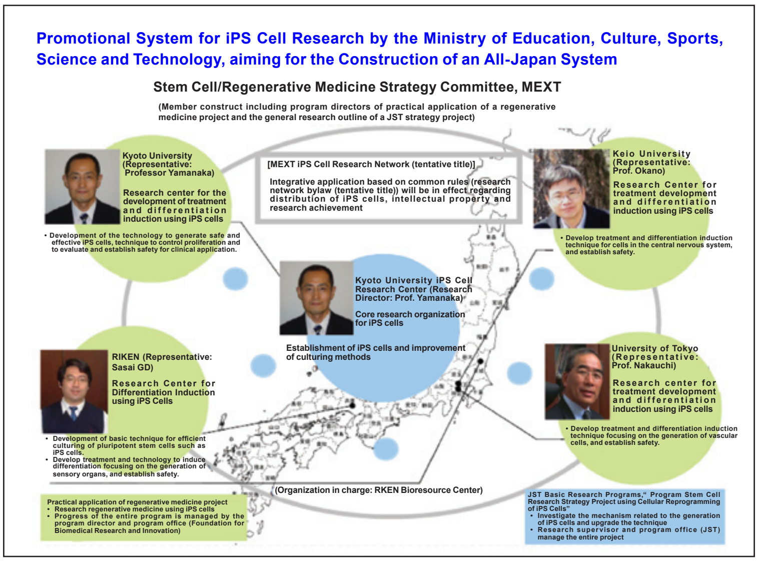


Figure : Promotional System for iPS Cell Research by the Ministry of Education, Culture, Sports, Science and Technology, aiming for the Construction of an All-Japan System

Provided by reference[20]

(Original Japanese version: published in March 2009)

Enviromental Sciences

2 Recycling Conducted by Material Industries: Current Conditions and Hindering Factors

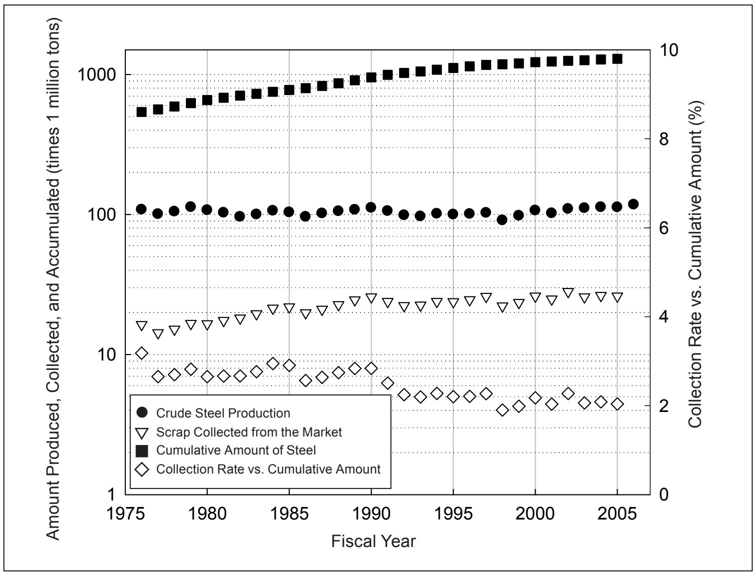
p.22

Recycling requires a number of steps, namely collection, (dismantlement and) sorting, and the actual recycling. In particular, the major characteristic of the recycling process is that the material industries of ferrous steel, nonferrous metals, paper, and other materials play a major role in commercial recycling.

These material industries acquire substantial amounts of recyclable materials; however, the actual percentage of recycled materials found in their final products (material recycling rate) is not particularly high. For example, only about 24% of steel materials consist of scrap collected from the market. There is still a long way to go before recycled materials cover most of the demand.

Material recycling can be divided into a number of subtypes: upgrade recycling where high-grade material is reproduced from recycled material; closed-loop recycling where mostly the same material is collected for recycling; and cascade recycling where waste products are only recycled into low performance materials. Currently, cascade recycling is the most common type of recycling. However, in the future, it will be necessary to create a system where closed-loop recycling for high-grade materials is also common. It will also be essential to develop separation and production technology to make upgrade recycling possible to some extent. To do so, funding for studies to develop separation technology at universities and public research institutes is essential, and governments also need to take the initiative in encouraging companies to conduct manufacturing development. Additionally, companies need to develop products that can be recycled easily, and, in order to make closed-loop recycling as common as cascade recycling, companies need to develop technology to be able to properly separate one material from another after dissolution or dismantling.

Recycling is an issue that concerns society as a whole, including residents, other generators of waste, the industries collecting and dismantling waste, and users of recycled materials. It is essential that governments, residents, and industries continuously discuss and do what they can. Governments also need to take the initiative in creating long-term goals and guiding the private sector towards those goals.



Figure：Steel Production and Recycling

Prepared by the STFC based on Reference[2]

(Original Japanese version: published in February 2009)

Enviromental Sciences

3 World Research Trends in Child Health and Environment

p.34

In recent years there has been a growing worldwide concern about the vulnerability of children to environmental changes, and studies have been conducted in countries around the world to gain an understanding of the relationship between the environment and children's health and to protect children's health. Children's developmental processes and their sensitivity to environmental changes differ depending on the developmental phase. As such, it is very important to study the effects of the environment over long periods of time from before birth to youth.

In particular, in the United States the Executive Order on the Protection of Children from Environmental Health Risks and Safety Risks was issued in 1997, and an interagency research project on children's environmental health and disease prevention was launched. In addition, in 2000 the Children's Health Act authorized the National Institute of Child Health and Human Development to carry out research on children nationwide; preparations for that research have been progressing. Additionally, a large epidemiological study was launched in January 2009. The study receives annual funding of more than 100 million dollars. In Japan, the Ministry of Environment has been exploring issues of children's environmental health and is planning to carry out a study on some 60,000 children nationwide starting in fiscal 2010, aiming to follow them from before birth until age 12. There are several other studies in Japan including the First Longitudinal Survey of Babies in the 21st Century by the Ministry of Health, Labour and Welfare. However, in contrast to the studies in the United States, which are being conducted as comprehensive national projects covering all factors, the studies in Japan are being planned and conducted individually, and so there is a difference in national strategy. When considering the difficulty of carrying out a cohort study and correlating diverse factors concerning child health and development, it becomes necessary from the perspectives of scientific rationality and research efficiency to find ways to verify objectives and hypotheses in each field on a common basis.

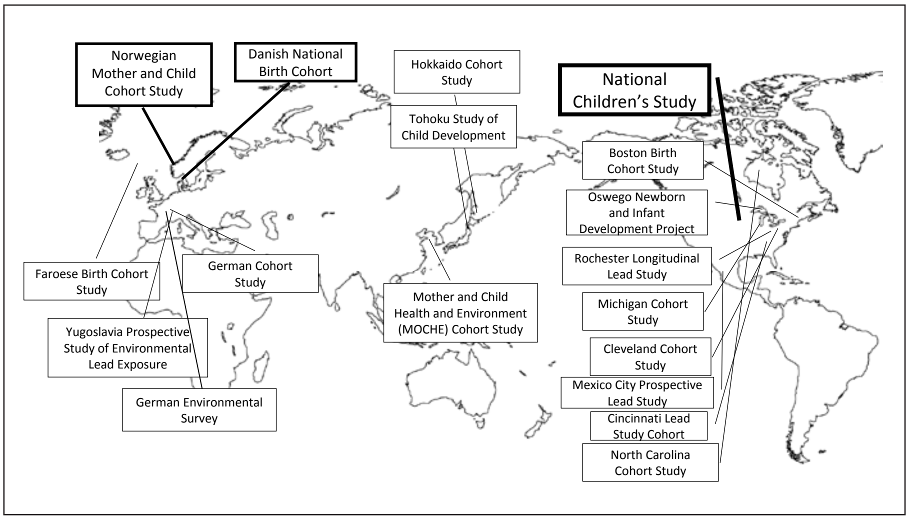


Figure : Major Cohort Children's Studies on the Environment and Health around the World

The reference[3] was partly modified by STFC

(Original Japanese version: published in March 2009)

Nanotechnology and Materials

4

Trends in Research and Development of Nanoporous Ceramic Separation Membranes
- Saving Energy by Applying the Technology to the Chemical Synthesis Process -

p.43

Currently, there are strong demands for energy-saving in the chemical synthesis process, including the distillation of petroleum refined products and isomeric separation, as well as for the downsizing of the synthesis process itself. Energy consumption in the chemical industry accounts for about 15% of the consumption in the entire industrial field, and about 40% of such energy consumption is accounted for by separation and refinement through distillation operations. Organic polymer separation membranes, which have so far been used in these processes, have limited heat resistance, chemical resistance, pressure resistance and mechanical strength. Through the use of nanoporous ceramic separation membranes, it could become possible to achieve groundbreaking energy-saving as well as the downsizing of space necessary for refining plants, which are both important requirements in the chemical synthesis industry. Japanese technologies related to nanoporous ceramic membranes using the typical ceramic zeolites, although still at the basic research stage, are currently at the highest level in the world. However, in order to develop a separation membrane system for practical application while also maintaining the advantage in basic technology, it is necessary to improve the structure of the R&D project. It is considered that the project structure, wherein processes including the development of membrane components and verification tests/evaluations at small plants are implemented at the same time, and wherein research and development on components, modules and system technologies are promoted simultaneously, should be made more effective so that problems in each fundamental technology necessary for practical application are shared from the beginning, and that actions are taken to address the problems in terms of practical application and commercialization through verification tests at small plants.

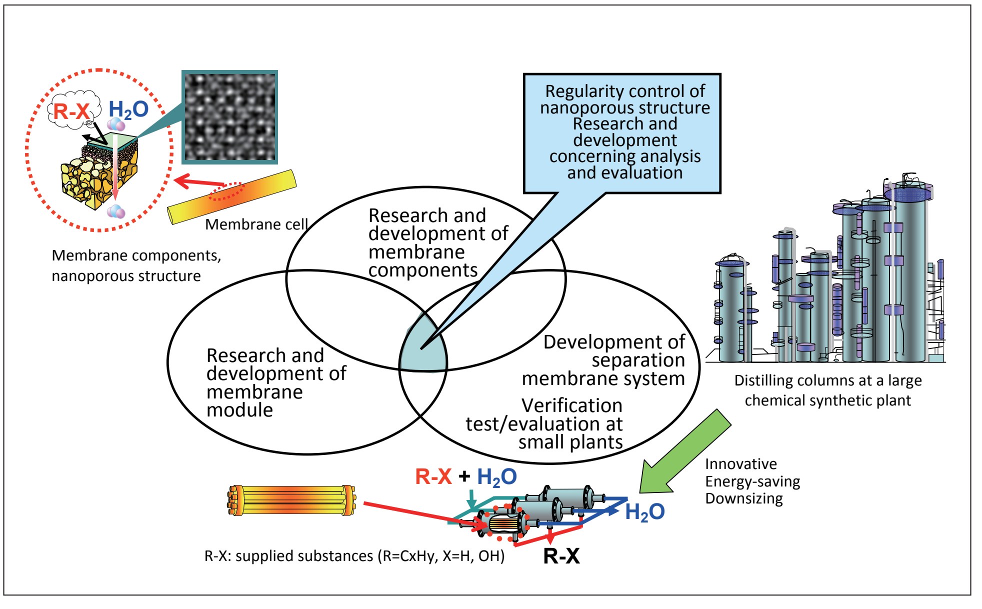


Figure 9 : Research and development topics for the application of nanoporous ceramic separation membranes system in the chemical synthesis process

Prepared by the STFC

The important topics of the research and development mentioned above include: membrane components that enable the thinning of membrane through regularity control of the shape and diameter of nano-size pores; manufacturing and processing technologies for porous ceramic support substrates that allow the relevant substances to permeate and be efficiently selected at the molecular level; technologies related to the establishment of a module system; and the establishment of technologies to analyze and evaluate the porous structure at the atomic level, which serves as the basis for the technologies mentioned above.

(Original Japanese version: published in February 2009)

Energy

5 Energy Saving Lighting Efficiency Technologies

p.59

Japan is obligated to reduce its greenhouse gas emissions with the entry into force of the Kyoto Protocol, but in reality, emissions have increased in comparison with the base year. Stricter measures are required particularly for reducing the use of fossil fuels. Lighting, which consumes more than 10 percent of the total electricity output in Japan, is one area in which energy can be saved.

Two measures are considered for improving lighting efficiency. The first measure is to maintain the same amount of light while consuming less electricity by improving the efficiency of lighting fixtures. Efficiency has been improved in both light bulbs themselves and lighting circuits, as typically seen in fluorescent lamps. New light sources such as light-emitting diodes (LEDs) and OEL, which are expected to increase energy efficiency to a large extent, have also been developed. The second measure is to improve efficiency in lighting methods regardless of the types of lighting fixtures used. Lighting methods in which required areas are illuminated at required levels of brightness are under development.

To promote lighting efficiency, it is necessary to establish legislation and nurture engineers in addition to improving the technology of lighting elements and fixtures. Efficient lighting is one energy-saving effort that households can achieve, but it is necessary to continuously conduct surveys and publish data on, for example, the ratio of electricity consumed by lighting to overall power consumption in order to increase the awareness of citizens and keep them informed. The need for energy-saving efforts never ends even when some targets are achieved, but should be continued towards the “zero waste” goal.

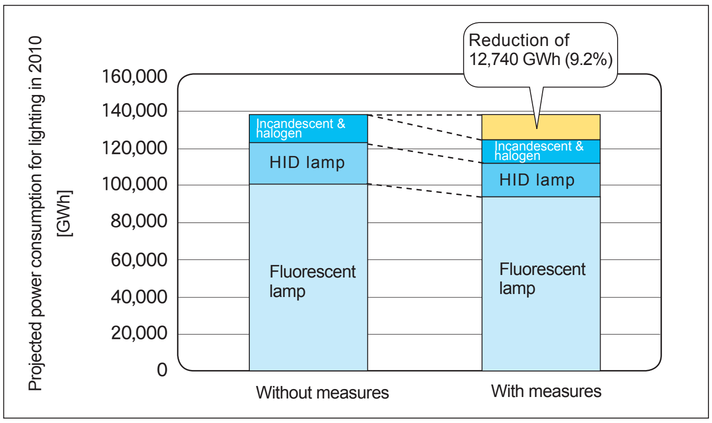


Figure : Energy-saving effects of replacing lamps with more efficient alternatives

Prepared by the STFC based on Reference[4]

(Original Japanese version: published in January 2009)

Social Infrastructure

6 Trends of Technology for Observing and Forecasting Localized Rains

p.72

Over recent years, heavy rains that are localized and last for a short time have grown more frequent in Japan, causing disasters. Cumulonimbus clouds that bring localized heavy rains are generated to trigger rainfalls in a very short time. Radars for remote sensing are an effective means for observation of rains. As nationwide radar systems, Japan has a weather radar network with the Japan Meteorological Agency to monitor rains and a radar rain gauge system from the Ministry of Land, Infrastructure, Transport and Tourism to manage rivers and roads.

Radars subject to recent research and development include multi-parameter and phased-array radars. The multi-parameter radar for accurate observation of rains and the phased-array radar for quick observation are considered effective for observing rains from fast-developing cumulonimbus clouds.

Weather phenomena can be explained by laws of physics. Numerical predictions using the laws constitute the core of weather forecasts. But actual weather phenomena depend on so many factors that it is difficult to focus forecasts on localized heavy rains as a tiny part of global atmospheric phenomena. Upgrading of numerical prediction models can contribute to improving the accuracy of forecasts. In addition, actual phenomena should be accurately reflected in numerical prediction models to build highly reproducible numerical prediction models. In this respect, it is important to find mechanisms for rains. In the future, Japan should develop highly accurate observation equipment, conduct precise observations using them, accumulate observation data and promote research and development of numerical prediction technologies that accurately represent the laws of physics based on these data.

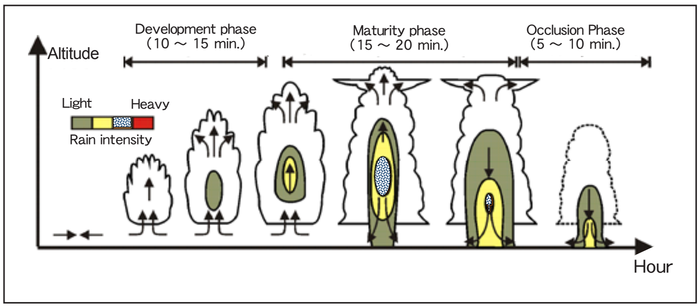


Figure 5 : Conceptual Diagram of Cumulonimbus Cloud's Life

Reference[7] as modified partially by the STFC

(Original Japanese version: published in January 2009)

Social Infrastructure

7 Current Status and Future Issues of Volcanic Eruption Prediction Research

p.85

There are 108 active volcanoes in Japan, and policies have been implemented to protect people's lives from volcanic eruption disasters. The volcanic eruption prediction programs that have been promoted by the Geodesy Council since 1974 ended in FY2008, and, from FY2009, they will be integrated with earthquake prediction programs to launch a new observation research program for the prediction of earthquakes and volcanic eruptions. Regarding volcanic disaster prevention, the Japan Meteorological Agency began providing information on eruption warnings and eruption alert levels in December 2007, which clarified not only volcanic activity status but also specific disaster prevention measures. In reality, however, volcanic eruption prediction research is still in the developmental process in terms of identifying the eruption mechanism, and is faced with two problems: low accuracy of provided information, and the vulnerability of the observation framework as well as the difficulty in maintaining standards.

For the future, it is necessary to establish an eruption prediction system that enables volcanic activity prediction by first creating eruption mechanism models and eruption scenarios based on basic research, and then linking them with high-quality data obtained from observation networks. In addition to promoting basic research, volcanic eruption prediction research is heading toward providing information that contributes to volcanic disaster prevention with higher accuracy, as well as utilizing the information.

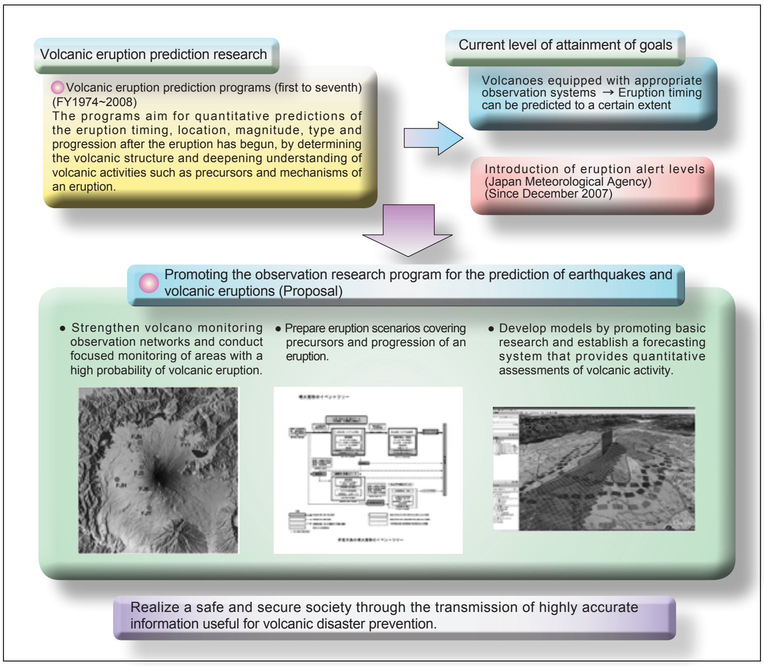


Figure : Direction of future volcanic eruption prediction research
Prepared by the STFC based on References[2,24]

(Original Japanese version: published in January 2009)

Social Infrastructure

8 The Role of Operations Research to wards Advanced Logistics

p.102

Product supply chains of recent Japanese industries are now at a major turning point as they attempt to cope with structural changes due to the globalization of industrial operations and changes in the relationships between related firms, and more advanced functional requirements, such as adaptability to volatile markets, energy conservation, response to environmental issues. Naturally, supply chain logistics of the products and services is also under pressure to reform and adopt more advanced operation technologies suited to these circumstances. In the planning and operation of complex and widely spread activities in the recent logistics, adaptation of mathematical analysis and optimization techniques by using operations research (OR) methodology is strongly required. Moreover, together with promoting application of OR, the development of more advanced OR techniques is also required.

Not only through the conventional improvements in the hardware aspect, such as transportation facilities and equipment, applying OR to logistics network design and optimization problems makes it possible to realize more efficient logistics operation through optimized warehouse location and inventory allocation in the large-scale distribution and transportation networks. It would also helps prevention of global warming by efficient transportation. However, in Japan, application of OR to logistics is not as popular as in Europe and the United States, and practical research in the universities is not active.

In order to respond to the issues in today's logistics, and to solve the problems of the future, research and development of advanced OR techniques together with research for problem solving should be essential. As a recent challenge, logistics would be an important field of the research in service science that is a hot issue in Japan to increase productivity and improve quality in the service industry, which accounts for a major part of the industrial structure. For enhancement of the research in logistics, both prioritizing science and engineering, and promotion of interdisciplinary research with fields of social science such as economics are required. It is also necessary to promote joint interagency and interregional research across the different institutions in various government offices.

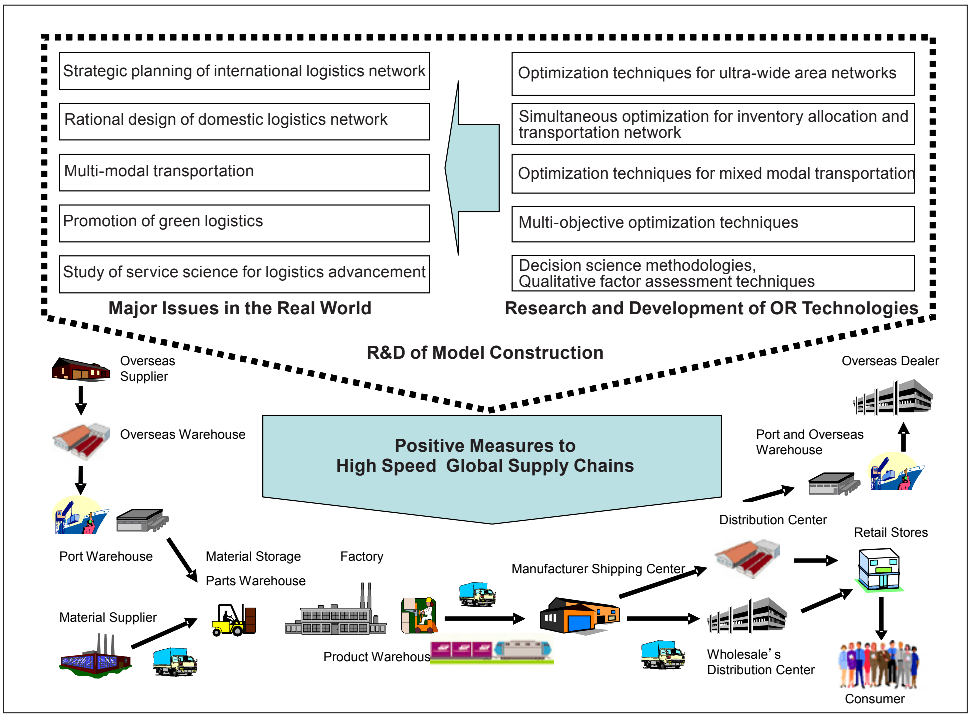


Figure : Real problems requiring solution R&D on model construction methods

Prepared by the STFC

(Original Japanese version: published in October 2008)

1

Trends and Challenges in iPS Cell Research

Yoshihiko SUMI
Affiliated Fellow

1 Introduction

1-1 What are iPS Cells?

Our bodies are composed of cells differentiated into each organ within the limited period after fertilization, and the process of differentiation was long believed to be irreversible.

The advancement of research in cell differentiation, however, revealed the existence of stem cells possessing multi-potency after body development with the discoveries of embryonic stem cells (ES cells) by culturing early embryo and mesenchymal stem cells, multipotent cells in our bodies. Since then, there have been extensive efforts to find and obtain these multi-potent cells.

In August 2006, Professor Shinya Yamanaka of Kyoto University succeeded in generating cells with pluripotent differentiation potential in mice by inserting just four genes (Oct3/4, Klf4, Sox2, c-Myc) into their mature skin cells, and named them induced pluripotent stem cells (iPS cells).[1] This groundbreaking new fact, which differentiated mature cells possess pluripotency, overturned the traditional belief that differentiation after fertilization was a one-way process and proved that it was rather a plastic phenomenon. The four genes required to induce pluripotency are called Yamanaka factors. In addition, on July 20, 2007, one year after the discovery of iPS cells in mice, Prof. Yamanaka and his colleagues reported and proved that iPS cells could be generated with human cells.[2] This, in other words, means that "a large amount of differentiating cells with the identical genes of the patient" can be prepared whenever necessary.

Human iPS cells were produced by inserting the same four genes (Oct3/4, Klf4, Sox2, c-Myc) used for murine iPS cells. Their method was simple and required no special equipment or technique, and was thus highly versatile. In addition, Prof. Yamanaka reported that insertion of only three genes (Oct3/4. Klf4. Sox2) could achieve iPS cells[3] making the method safer without the use of carcinogenic c-Myc gene. Moreover, the initial method using retrovirus vectors[NOTE 1], a possible carcinogen, is now improved with the use of plasmid vectors[NOTE 2] with less carcinogenic risks.[4] Plasmid vectors, with their ability to insert genes without damaging the genes of the targeting cells, are believed to be safer than retrovirus. Recently, a group from Max Plank Institute for Molecular Biomedicine in Germany succeeded in producing murine iPS cells by inserting only one gene, Oct4, with some chemical agents[5].

1-2 Expectations for Science and Medicine

The importance of the discovery of iPS cells, as mentioned above, is the demonstration that the ability to differentiate into various organs was not exclusive to fertilized oocytes, but differentiated cells could achieve pluripotency as well with gene insertion. This proved the novel concept that pluripotency in differentiated cells could be re-set to a similar level as fertilized oocytes of early embryo. In other

[NOTE1]
Retrovirus vectors are used to carry the genes to be inserted into the target cells.
[NOTE2]
Plasmid vectors are non-viral cyclic DNA gene carriers for gene insertion.

words, it changed the entire strategy from "searching for" pluripotent cells to "generating" them with the establishment of an innovative technique that have the convenience of being able to "prepare whenever necessary," thus providing "pluripotent cells with individually conserved genetic character" at all times.

The expected benefits of iPS cells go beyond research to applications in medicine and drug development with their potential for generating appropriate cells whenever necessary. Expectations are high especially in (1) application in drug development where evaluation of the safety and efficacy of candidate compounds can be done with human cells and tissues differentiated from human iPS cells rather than traditionally used animal tissues or cells, (2) application in regenerative medicine for patients who need repair and regeneration of tissues or function disordered in a disease by regenerating and grafting tissues and organs generated from iPS cells derived from the patients' own cells, (3) in preparation of establishing an iPS cell bank with a collection of various types of human iPS cells, ready to provide a wide range of patients at any time, and (4) for treatments of congenital and intractable diseases[6, 7].

2 Scientific Innovation Triggered by iPS Cells

2-1 Application for Drug Development

The earliest practical application of iPS cells is expected to be in the field of pharmaceutical research for developing new drugs.

The best way to evaluate the safety and efficacy of most drug candidates is with humans, though this comes with many risks. In addition to the obvious risks, since access to human cells and human disease model cells has been widely limited, these evaluations have been conducted mostly with animal cells and animal disease models such as mice. There are many issues, however, with the evaluations using animal models, such as a long development period. In addition, there have been incidents of finding unforeseen side effects and altered efficacy after the drug had been on the market due to frequent interspecies differences between humans and the animal model, in toxicity and efficacy.

With the discovery of iPS cells, drug efficacy can be evaluated with human disease models differentiated from iPS cells derived from patients with the target disease right from the start. In addition, this technique allows access to certain cell types that are impossible to obtain from actual humans, such as cerebral neurons and cardiac muscle cells, and use them in evaluation. The use of iPS cells is expected to speed up the drug development process as well as obtain more information about side effects due to highly accurate evaluation with human cells.

Research and development of a toxicity-evaluation tool using human cardiac muscle cells generated from iPS cells started in October 2008 as a commissioned project of the New Energy and Industrial Technology Development Organization (NEDO). This project aims to establish a technique to evaluate early cardiac toxicity using iPS cells, with their technology to measure the pulsation of cardiac muscle cells developed in the existing NEDO project [8]. Since human myocardial cells were difficult to obtain, drug evaluation had to be conducted with animal model cells such as mice. With the available technology to generate human myocardial cells from iPS cells, efficacy and side effects of candidate drugs can be evaluated directly, enabling the development of drugs with better efficacy and fewer side effects in the future. In addition, omission of evaluation with animal cells is expected to contribute to a shortened development period and reduction of development cost.

The National Institute of Biomedical Innovation has produced iPS cells from patients with various diseases and is planning to differentiate them into cells such as hepatic cells, which are required for the evaluation of the toxicity, and metabolism of candidate drugs. This project is aiming to establish a technology for drug development by preparing iPS cells and differentiated cells derived from iPS cells of different sexes, ages, cell types and genetic backgrounds. Subsequent contribution to the improvement of drug safety (due to detailed toxicity evaluation in screening) is expected.[9]

In the future, the application of this technology will go beyond general drug development, and enable a pre-administration check of drug efficacy and toxicity with the cells differentiated from iPS cells derived from the patients' own cells, allowing optimization of the dosage and prevention of side effects by applying it for individual administration management and detailed individual treatment.

2-2 Application for Regenerative Medicine and Cellular Medicine (Treatment with Autologous Cells)

One of the biggest dreams with iPS cells is their application in regenerative medicine. This is due partly to their pluripotency. The difficulty of obtaining necessary cells for treatment has slowed down regenerative medicine as cell therapy. However, the discovery of iPS cells, cells possessing pluripotency made from skin cells, has shed hopes for abundant access to iPS cells for regenerative medicine and necessary cells and/or tissues differentiated from them for graft treatment (Figure 1).

The discovery of iPS cells has also shed special attention to autologous cell treatment, a type of treatment using patients' own cells. This means, skin cells taken from a patient will be turned into iPS cells to obtain necessary cells and tissues via differentiation and culturing in order to use them for the treatment of the patient him/herself, the provider of the cells. Since these cells come from the patient, they will not be labeled foreign when they are returned in the body, and thus pose no risk of immunological rejection.

iPS cells are not ideal for emergency use since it takes more than a few weeks to generate them. However, in cases where disease onset can be predicted, new medical divisions such as "emergency responsive medicine" and "preventative medicine" may now be operable. For example, for patients with high risks of cardiac infarct, preparation of myocardiac cells differentiated from iPS cells generated from their cells is now possible before the infarct attack.

A research team at the University of Tokyo, led by Professor Hiromitsu Nakauchi, has succeeded in differentiating iPS cells generated from human skin cells into thrombocytes via megakaryocytes by adding growth factors and co-culturing with bone marrow cells. This knowledge enables the generation of blood-related cells, such as white blood cells and red blood cells, and the concept of blood transfusion will be changed greatly in the future.

In January 2009, the Food and Drugs Administration (FDA) of the United States approved Geron Corporation, an American venture company, to conduct a clinical test to treat eight to 10 patients with paraplegia[NOTE 3] with human ES cells[10]. This is the world's first clinical test using human ES cells, and the United States is expected to take the lead in the field of iPS cell application as well.

iPS cells will be applied in regenerative medicine in the near future when the safety of iPS cells is verified and safe differentiated cells derived from iPS cells are established.

2-3 Use of Cell Bank (Homologous Cell Treatment)

Another approach for cell therapy using iPS cells is to make them more general by building cell banks. This is not only for autologous cell therapy where iPS cells are used only for the provider of the cells but also for cell therapy for all patients, which is termed homologous cell therapy (human to human, using another person's cells).

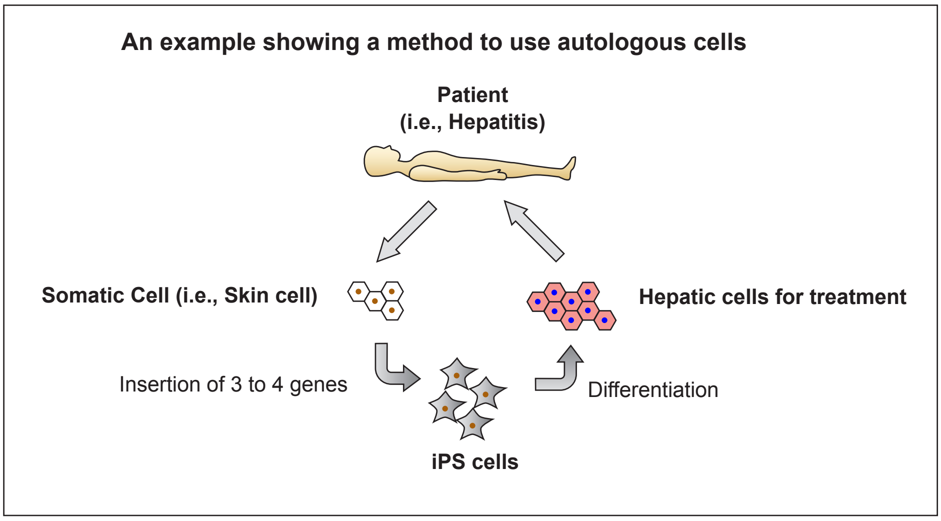


Figure 1 : Conceptual Diagram of Augologous Celll Therapy
(Conceptual diagram showing autologous cell therapy using iPS cells)

Prepared by the STFC

Human cells have different types of histocompatibility antigen (HLA) on the cell surface, and a mismatch in the antigen type is recognized as foreign and subsequently triggers immunological rejection and elimination. According to a calculation by Professor Norio Nakatuji and his colleagues of the Institute for Frontier Medical Sciences of Kyoto University, to eliminate a mismatch that causes the immunological rejection, preparation of 170 different types of iPS cells can be used for 80% of the Japanese population[11, 12]. This suggests a possible use of iPS cells produced by other people's cells in graft treatment in regenerative medicine by preparing many different HLA type cells to minimize the risks of rejection.

Treatment using this type of cell bank has been proposed by Professor Hideyuki Okano of Keio University. For cell therapy in a life-or-death emergency, such as treatment of spinal damage where grafting of nerve cells is ideally conducted on the 9th day post injury, iPS cells of the patients cannot be prepared in time. Therefore, for cases like this, it is ideal to build a bank within a cell bank for iPS cells without immunological rejection as well as a nerve cell bank using iPS cells for the treatment for spinal cord injury.[13]

One example of current progress was demonstrated by principal research associate Hajime Ogushi of the National Institute of Advanced Industrial Science and Technology, who has succeeded in producing iPS cells from mesenchymal stem cells contained in pulled wisdom teeth. Since wisdom teeth were traditionally discarded, they are regarded as a great candidate for the cellular source for building an iPS cell bank[14].

Resources at the iPS cell bank and cell bank derived from iPS cells for treatments are now expanding from homologous to heterologous cell therapy, and they are expected to be applied for emergency treatment of frequent injuries.

2-4 Treatment of Congenital and Intractable Diseases

iPS cells are expected to open up a new way for the treatment of congenital and intractable diseases presently with no radical cure. This involves generation of iPS cells from the cells of patients with congenital diseases or genetically intractable diseases, their differentiation following the repair of damaged genes at the DNA level, and grafting them back to the body to regenerate normally functioning tissues and/or organs. Alternatively, the treatment could be done by grafting normal healthy cells derived from iPS cells to the lesions of patients with intractable diseases. Hemophilia, congenital immunodeficiency and Parkinson's disease are among the target diseases.

Already, a research team at Harvard University in the United States has reported that they produced iPS cells using skin or bone marrow cells of patients with 10 different diseases, such as dystrophy, Down syndrome, diabetes and Parkinson's disease.[15, 16] Another research team at Harvard reported a successful generation of iPS cells from elderly patients with amyotrophic lateral sclerosis (ALS) for the same purpose[17]. The United States seems to be leading the application of iPS cells by far at the moment.

In our country, collaboration between Kyoto University and Keio University has lead to a report at a Keio University symposium on February 4, 2009, that the grafting of nerve cells differentiated from human iPS cells into mice with spinal injuries on the ninth day post injury has resulted in significant recovery of motor ability compared to mice receiving no treatment post injury. This, though a preliminary experiment using mice, is the first case to show the efficacy of iPS cells in an animal disease model.

At Osaka University, in collaboration with Kyoto University and Tokyo Women's Medical University, a myocardiac sheet was constructed with myocardiac cells differentiated from iPS cells derived from mouse fibroblast. When this myocardiac sheet was grafted in the infarct region of a cardiac infarct model created by ligation of the left anterior descending artery in mice, improvement in cardiac dysfunction and the suppression of a left ventricle enlargement was found.[18]

2-5 Repairing Organs

Yet another new challenge has started to re-construct normally functioning organs and tissues by producing iPS cells from patients with acquired dysfunction in some parts of the body and by re-differentiating them inside the patient's body.

Professor Nakauchi at the Institute of Medical Science of Tokyo University has cultured fertilized

[NOTE3]
Paralysis in both legs below the waist

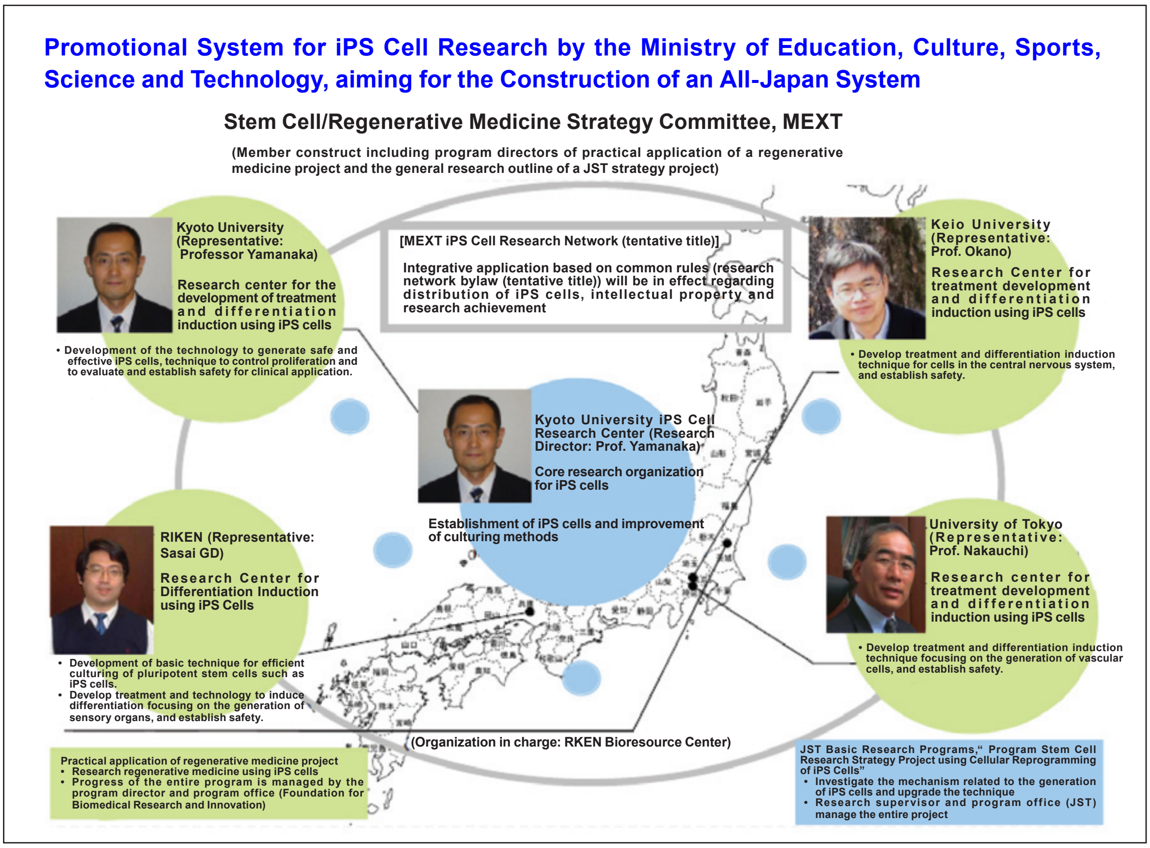


Figure 2 : Promotional System for iPS Cell Research by the Ministry of Education, Culture, Sports, Science and Technology, aiming for the Construction of an All-Japan System

Provided by reference[20]

oocytes, taken from mice with a deficit of genes to form a pancreas, to blastocyst and then injected iPS cells produced from normal mice. These blastocysts were subsequently implanted in a surrogate mother, and the resulting offspring formed pancreases with normal functions. Similarly, they have succeeded in forming kidneys, and the generation of these organs with bigger animals, such as pigs, is expected[19]. If this method proves to be successful in pigs, kidney transplants for patients with severe kidney dysfunctions are no longer just a pipedream since kidneys can be produced from differentiated iPS cells derived from the patient and by injecting them into pig blastocysts.

3 Research System

3-1 National Research Collaboration System

As mentioned above, iPS cells are expected to be a source for drug development research as well as tools for frontier treatment for diseases. In addition, since this was discovered first by Prof. Yamanaka of Kyoto University, an "All Japan System" for research is now being constructed in order to lead in basic research and their use in the industry (Figure 2).

For the "Project to Achieve Regenerative Medicine," four organizations, Kyoto University (Representative: Prof. Shinya Yamanaka), Keio University (Representative: Prof. Hideyuki Okano), University of Tokyo (Representative: Prof. Hiromitsu Nakauchi) and RIKEN (Representative: Dr. Yoshiki Sasai, Group Director), were chosen to strengthen the research using human iPS cells. With these four core institutions, they formed a network devoted for iPS cell research using human iPS cells, with each institution progressing in the research responsibly (Table 1).

As a core institution to progress iPS cell research in our country along with the four core organizations, the Center for iPS Cell Research and Application (CiRA: Research Supervisor: Prof. Shinya Yamanaka) was founded at Kyoto University in January 2008. CiRA is in charge of developing a safe and efficient technique to produce iPS cells, developing growth control technology, establishing safety for clinical application and developing necessary technology for the application. In details, it sets eight goals, shown

Table 1 : Four Research Centers Chosen as Human iPS Cells Research Centers and Abstracts of their Research

Title		
Title	Representative Researcher	Abstract
Integrative Research Center for iPS Cell Research at Kyoto University		
Kyoto University	Shinya Yamanaka	In order to advance human iPS cells research correctly and quickly from its initial stage for their use in regenerative medicine, we aim to contribute not only in Japan but around the world by collaborating with rich resources of researchers at the Institute for Frontier Medical Sciences, Kyoto University Hospital and the Institute for Integrated Cell-Material Sciences, as well as with organizations outside of Kyoto University, such as Osaka University, with CiRA as the core research center. Goal: 1) To reveal the basic essence of iPS cells, 2) to develop safe and effective methods to generate iPS cells, 3) to develop technology to control proliferation and differentiation induction of iPS cells, 4) to develop treatment technology using differentiated cells in disease-related projects, 5) to establish safety and evaluation techniques for clinical application, 6) to build a system to manage and operate intellectual property related to iPS cell research, 7) to found a basis of medical ethics specialized for iPS cells, 8) to standardize an iPS cell-generation technique, and to tirelessly progress iPS cell research in Japan with effective collaboration with related organizations outside of school, active utilization of resources of researchers and by sharing information.
Research Center for Practical Application of iPS cells, ES cells and Somatic Stem cells in Regenerative Medicine		
Keio University	Hideyuki Okano	We aim to deepen our basic knowledge of the mechanisms of autonomous replication, differentiation and epigenetic control and culturing techniques on human iPS cells, ES cells, and somatic stem cells. In order to achieve actual practice of regenerative medicine, we aim to progress internationally top-level clinical research with primate models, to verify safety and efficacy with the use of these iPS cells, with a special focus on diseases involving the central nervous system, hepatopoietic system, cardiovascular system and sensory system. In addition, build a firm basis of human iPS cell research by generating and self-processing many different HLA types of human iPS cells.
Development of Next Generation Gene and Cell Therapy Using iPS Cells		
University of Tokyo	Hiromitsu Nakauchi	With the Center for Stem Cell Therapy Research at the Institute of Medical Science Research, as the core research center, organize a collaborative research system with 4 departments—the Department of Medical Research, University of Tokyo Hospital, Institute of Molecular and Cellular Biosciences and the Graduate School of Arts and Sciences—we aim to advance research in preparation of preclinical tests. As well as establishing a system to generate high quality human iPS cells derived from patients with careful consideration of safety and ethics, we aim to develop a system to regenerate a variety of organs such as blood, blood vessels, bone. cartilage, skeletal system, cardiac muscles, liver, pancreas and nerves from iPS cells. In addition, we also aim to develop new methods of gene-repair treatments using the characteristics of iPS cells for diseases such as hemophilia and congenital immunological dysfunction as well as to educate resources of researchers in regenerative medicine.
Total Center for Technological Development of Differentiation Induction/Grafting as well as Technological Support for Human Pluripotent Stem Cells		
©RIKEN	Yoshiki Sasai	We conduct technological development for highly efficient differentiation induction of human ES cells and iPS cells into neuronal, sensory and blood cells. At the same time, we aim to develop a culturing technique to improve safety, and to establish the basic methods for purification of generated usable cells. In addition, through grafting research using animal models, analyze their function in vivo, and establish the basis for medical application such as in cell therapy. In particular, with the goal of a practical use of human iPS cells, conduct preclinical tests on medium-sized animals for grafting of retinal cells (pigment epithelial cells), and establish a technology that is clinically applicable for age-related muscular degeneration and pigmentary retinal degeneration Through the collaboration between the main research center (Center for Developmental Biology) and the secondary research center (Bioresource Center) as a support center, contribute to the development of technology, resources and infrastructure by providing lecturing and transferring techniques, building, banking and providing useful cell strain, and by adjusting protocol in order to apply human stem cells such as iPS cells in regenerative medicine research in Japan.

Prepared by the STFC based on Reference[21]

in Table 1, and takes charge of basic research to reveal the essence of iPS cells and to develop a safe differentiation induction technique.

Keio University is the research center for practical application of iPS cells in regenerative medicine. They are in charge of applying their knowledge and expertise from their prior research of practical use of stem cells with ES cells and somatic stem cells before the discovery of iPS cells. In addition, in order to use iPS cells for the diseases shown in Table 1, they are aiming to achieve regenerative medicine by driving forward pre-clinical research, including tests with a primate model and confirmation of its safety. They focus on the development of a differentiation technique (especially in the central nervous system), confirmation of safety and research for treatment development. In addition, they have their eye on constructing iPS cell bank with many HLA type human iPS cells (goal: 200 strains) to target diseases in the central nervous system, hematopoietic system, cardiovascular system, and sensory system.

At the University of Tokyo, lead by the Stem Cell Treatment Research Center at the Institute of Medical Science Research, development of differentiation induction, safety confirmation and treatment development technology research will be undertaken. In addition, they will investigate specific diseases shown in Table 1.

At RIKEN, the development of basic technology for efficient culturing of iPS cells, the development

Table 2 : Major iPS Cell Research Organizations Other than the Four Selected Organizations and the Focus of Their Research

Research Organization	Research Focus
Tohoku University	Development of regenerative treatment using autologous cornea cells generated from iPS cells
Nagoya University	Development of novel vascular regenerative treatment using vascular precursor cells derived from iPS cells
Nagoya City University	Actualization of stem cell treatment for periventricular leukomalacia
Osaka University	Treatment of cardiac disease such as myocardiac hypertrophy using myocardial cells generated from iPS cells
Kyushu University	Development of a safe and highly efficient method to differentiate hematopoietic stem cells using human iPS and ES cells
Kumamoto University	Development of the basis for differentiation control from iPS cells to pancreatic βcells and for regenerative medicine for diabetes
National Center of Neurology and Psychiatry	Development of stem cell graft treatment for dystrophy
National Institute of Biomedical Innovation	Build evaluation database on pharmaceutical efficacy and side effects using iPS cells
National Institute of Advanced Industrial Science and Technology	Development of grafting treatment using genetically modified mesenchymal stem cell for severe congenital metabolic bone disease

Produced at Science & Technology Trends Research Center based on references[22-24]

of differentiation induction especially in sensory system as well as safety confirmation and treatment development will be undertaken.

Some universities and research organizations other than the four aforementioned organizations indicated in Table 1 have started research using iPS cells (Table 2). Most are researching with aims to develop treatment for congenital diseases and genetically intractable diseases.

3-2 International Research Collaboration

International research collaboration is still in the initial stage of relationship-building. As I will address later, there seem to be many difficulties to overcome to build a friendly international collaborative relationship with the current vigorous international competition for the rights to the intellectual property.

Under this condition, CiRA has agreed to form a partnership with an American corporation, Novocell, Inc. in September 2008, to research the differentiation of iPS cells to pancreatic cells. Novocell, Inc. has had previous success in creating pancreatic cells using ES cells, and now they will take the challenge of making pancreatic cells from iPS cells. This is aiming at the development of a radical cure for diabetes, and will be a big step in this area, anticipating high demand.[25]

In addition, CiRa has signed an agreement on research collaboration with the University of Toronto in Canada in October 2008. This was for exchanging information about the induction, maintenance and differentiation technique of iPS cells for studying pathological conditions and developing treatments for intractable diseases using disease-specific iPS cells created from the cells of the patients.[26]

The Japan Science and Technology Agency (JST) has concluded a collaborative agreement for stem cell research with the California Institute for Regenerative Medicine (CIRM) of the United States in November 2008. Based on the agreement, they will support various international collaborative research activities by hosting seminars and interaction among researchers and international symposiums. In addition, they are planning to improve the environment for research interactions through sharing and transmission of information about iPS cell research and by hosting a research retreat for young researchers in iPS cell research[27].

3-3 Importance of Strategy for Intellectual Property

As I have mentioned, iPS cells are expected to be used in the development of drugs and novel medical treatments. However, due to this industrialization, iPS cells will be an intellectual property and whenever they are used directly or indirectly, there will be a charge to be paid to the holder of the patent. Since iPS cells and the associated technology were first discovered by Kyoto University, they are believed to have an advantage in many technological contents which are to be patented. However, with the rapid cycle of research reports from many countries, such as the United States, a significant number of patents will likely be applied by these research organizations and corporations.

Publicized patent information to date indicates the first patent application on murine iPS cell generation by Kyoto University was on December 13, 2005 (Japanese Patent). Similarly, the international application date including human iPS cell generation methods (aforementioned Japanese application date is the priority date) was December 6. On the other hand, application dates from others include Wisconsin University in the United States on March 23, 2007, Massachusetts Institute of Technology's Whitehead Institute for Biomedical Research on April 7, 2007, Harvard University on May 30, 2007, and Bayer AG of Germany on June 15, 2007. Thus based on the application date, Kyoto University holds an advantageous position over the other patent applicants. In fact, on September 12, 2008, the first patent on the iPS cell generation methods by Kyoto University was accepted in Japan.[28] What is approved as rights, whether this patent is approved in other countries, and the approval of patents applied afterwards all depend on the content of the right requisition of patent application as well as the way that patents are regarded in each country. Therefore, it is necessary to pay attention to the transition in order to confirm whether the rights on truly necessary contents are protected.

Kyoto University has started their effort to control their intellectual property by first setting a specialized division, iPS cell research intellectual property support, in the Office of Society-Academia Collaboration for Innovation in April 2008, and subsequently in August 2008, Intellectual Property Office in the Research Strategy Division at CiRA.[29]

On the other hand, the Japan Pharmaceutical Manufacturers Association (JPMA) has proposed that it is necessary for there to be an all-Japan support system that includes the industrial arena's knowledge about strategy in intellectual property for iPS cell-related research accomplishment, at public and private dialogue with the ministers from Ministry of Economy, Trade and Industry, Ministry of Education, Culture, Sports, Science and Technology and Ministry of Health, Labor and Welfare in April 2008.[30, 31] However, at this time, consortium is yet to be achieved. JPMA has started their own action and founded an intellectual property support project in November 2008 with contributions from 13 companies on the executive board as one-year support, by analyzing and advising on the strategy for intellectual property of iPS cell-related research results, with a special focus on rights acquisitions in the United States.[32~34]

In June 2008, iPS Academia Japan was founded to manage patented intellectual property on an iPS cell-generation method by Kyoto University, and to approve the rights to conduct patent discovery for companies aiming to develop medical treatment and drugs using the method.[35] Their principle is to provide nonexclusive license for free to non-profit organizations, such as universities, and provide a nonexclusive license onerously to profit-making organizations. To date (February 2009), they have started negotiations with more than 10 companies.

4 Challenges in the Future

4-1 Standardization of iPS Cells

As we are still at the stage of gaining basic knowledge regarding the iPS cell generation, the definition of iPS cells -what exactly are iPS cells- is still vague. Standardization of iPS cells, criteria to define iPS cells, and technological development for standardization are urgently needed for practical application of iPS cells. In particular, clones with different differentiation abilities obtained in the process of generating iPS cells require basic verification, such as the difference between the clones (inter-clone variance) and the way to controlling the changes within one clone over culturing and successive subculture (intra-clone variance).

In the future, iPS cells are expected to be used all over the world, and Japanese research teams are desired to take a lead role in their universal standardization.

4-2 Treatment of Human Diseases

Development for treatment of diseases in humans is one of the major possibilities with the use of iPS cells. Therefore, we should focus on whether it is actually possible and if so how this can be achieved. Especially, efforts should be made to develop treatments for genetic diseases and intractable diseases without any existing treatment. In addition, their adaptation for regenerative medicine with high demands should be made immediately. As I stated in 2-5, the United

States seems to take the lead in this area using their resourceful achievement with stem cell research.

One of the greatest contributions of the iPS cell discovery to human kind is that it gives hope and expectations for treatment to intractable and congenital disease patients. Therefore, we need to select candidate diseases on which to focus, as well as organize teams of clinical doctors and develop researchers for each disease to tackle the target intractable and congenital diseases.

4-3 Guideline for Clinical Application

In order to achieve a successful application of iPS cells in regenerative medicine and disease treatment, we need to build a seamless flow from basic research to applied research. Currently, the guideline for clinical tests using human iPS cells[36] seems to be applicable for tests using iPS cells. However, it is important to construct a guideline specifically for iPS cells that actively guides a user through basic research to their application, following the evaluation of 1) efficacy (benefit) and 2) safety (risks) of iPS cells, to achieve appropriate and speedy application using the results obtained. Therefore, research institutions, directing ministries and the industry should interact with each other to hold detailed yet active discussions in order for each opinion to be reflected directly on the guideline.

The FDA in the United States has already permitted Geron Inc. to conduct a clinical test using ES cells. In addition, in March 2009, President Obama signed an Exclusive Order to lift restrictions on federally funded embryonic stem cell research. Since the knowledge obtained from ES cell research is applicable to iPS cells, clinical application of iPS cells in the United States is expected to accelerate in the future.

In Japan, the application of regenerative therapy to patients has lagged behind the Western countries in the past due to overly strict policy for regenerative medicine as well as delayed revision of science and technology policies as they advanced. We can only hope for a quick setting of the policy for the clinical application of iPS cells. If, however, the policy is too conservative, the development of Japanese iPS cell therapy will be limited. This may result in the American medical industry and their supporters, with liberal approval to polish their pioneering medical technology, to reap all of the reward alone.

4-4 Strategy for Intellectual Property

As I mentioned, practical application of iPS cells is expected to start with the application for drug development followed by use in cell therapy. In particular, their clinical application for the treatment of intractable diseases is expected to be initiated by the United States following their first clinical application of ES cells to be conducted only about 10 years after their initial basic research. Considering the size of the market and the speed of practical application, it is important to get the patent in the United States as well as in Japan.

The method of generating iPS cells has been patented in Japan now. However, patenting of iPS cells themselves independent of their generation methods and of iPS cells and their differentiated cells derived from patients with intractable diseases is still the very basic aspect of the patents. In addition, although medical procedures could not be patented here, since they can be patented in the United States, a strategy to aim for an American patent is very important. For example, though both Europe and Japan have a "first come first served" policy on patenting, meaning the first submitted application is accepted even when the difference is only by a day or the content be identical, since the United States has "first to invent first served" policy, the date of the invention/discovery is critical and experiment notes act as important evidence. Therefore, the management of experiment notes of all researchers researching iPS cells is the basis for getting an American patent. At the "Life Science Intellectual Property Forum" on January 28, 2009, co-hosted by JPMA and the Japan Bioindustry Association, revision of the application method was discussed to include the American caveat policy to act on the ever so rigorous iPS cell-related research field with a shortening interval between new patent applications and presentations at academic conferences.

As shown here, considering the importance of the American patent of Intellectual Property, it is necessary to cooperate with those in the private sector who have extensive experience in obtaining American and international patents. In addition, patent application should be submitted as soon as a discovery is made in research, and in that sense, research and action for intellectual property rights need to be done simultaneously. Therefore, I emphasize the importance of the aforementioned system by JPMA, "iPS cell intellectual property consortium."

Presently, building a systemic strategy for obtaining intellectual property rights is the most urgent issue to overcome, with new research results coming everyday.

References

[1] Takahashi K and Yamanaka S, Induction of Pluripotent Stem Cells from Mouse Embryonic and Adult Fibroblast Cultures by Defined Factors, Cell 126, 663-676 (2006)

[2] Takahashi K et al., Induction of Pluripotent Stem Cells from Adult Human Fibroblasts by Defined Factors, Cell 131, 861-872 (2007)

[3] Nakagawa M., Koyanagi M., et al., Generation of Induced Pluripotent Stem Cells without Myc from Mouse and Human Fibroblasts, Nat. Biotechnol. 26(1), 101-106 (2008)

[4] Okita et al., Generation of Mouse-Induced Pluripotent Stem Cells Without Viral Vectors, Science 322(5903), 949-953, (2008)

[5] Kim JB et al., Oct4-Induced Pluripotency in Adult Neural Stem Cells, Cell 136, 411-419, (2009)

[6] Special Symposium "Impact of Pluripotent Stem Cell Research-Future of iPS Cell Research," held on December 25, 2007, Symposium Report HP for Japan Science and Technology Agency : http://www.jst.go.jp/report/2007/071225_ips_sympo_report.pdf (Japanese)

[7] Discussion about issues of iPS cells by international stem cell researchers, Science & Technology Trends, No. 87, June 2008, Topics : http://www.nistep.go.jp/achiev/results02.html

[8] Support policies for iPS cell research, Documents of Ministry of Economy, Trade and Industry : http://www8.cao.go.jp/cstp/project/ips/haihu1/siryo7.pdf

[9] Initiative collaborative research for practical application of iPS cells and conditioning of research system, National Institute of Biomedical Innovation HP : http://www.nibio.go.jp/cgi-bin/new/view.cgi?no=404

[10] Geron Receives FDA Clearance to Begin World's First Human Clinical Trial of Embryonic Stem Cell-based Therapy, Geron Inc. HP : http://www.geron.com/grnopc1clearance/grnopc1-pr.html Science & Technology Trends, March 2009,

[11] Nakajima F., Tokunaga K. and Nakatsuji N., Human Leukocyte Antigen Matching Estimations in a Hypothetical Bank of Human Embryonic Stem Cell Lines in the Japanese Population for Use in Cell Transplantation Therapy, Stem Cells 25, 983-985, (2007)

[12] Development of next generation gene and cell therapy using iPS cells, Next Life Science Portalsite, Ministry of Education, Culture, Sports, Science and Technology HP : http://www.lifescience.mext.go.jp/download/sr2/sr2-4.pdf (Japanese)

[13] International Symposium "Future Created by iPS Cell Research" held on May 11, 2008, Japan Science and Technology Agency HP : http://www.jst.go.jp/pr/jst-news/2008/2008-06/page05.html

[14] Establishment of iPS Cells from Teeth (Wisdom Teeth), Advanced Industrial Science and Technology HP: http://www.aist.go.jp/aist_j/new_research/nr20080825/nr20080825.html

[15] Park, I.-H., et al., Disease-specific Induced Pluripotent Stem Cells, Cell 134, 877-886 (2008)

[16] Generation of iPS Cells Derived Using Cells of Patients with Intractable Diseases, Science & Technology Trends, No.91, October 2008, Topics : http://www.nistep.go.jp/achiev/results02.html

[17] Dimos JT, et al., Induced Pluripotent Stem Cells Generated from Patients with ALS Can Be Differentiated into Motor Neurons, Science 321, 1218 - 1221 (2008) : http://www.cumc.columbia.edu/news/press_releases/stemcell-als-henderson.html

[18] Kenji Miki et al. Investigation of Regenerative Medicine for Cardiac Musclesusing iPS Cells Derived Myocardiac Cell Sheet, Regenerative Medicine 8, Suppl., 254 (2009)

[19] Hiromitsu Nakauchi, From Cell Therapy to Actual Organ Regenerative Medicine, Regenerative Medicine 7, Suppl., 74 (2008)

[20] Japan Science and Technology Agency HP : http://www.jst.go.jp/keytech/h20-1sanko.pdf

[21] Project for Practical Application of Regenerative Medicine, Agency for the Adjustments for Human iPS cell

Research Institution Organization, Japan Science and Technology Agency HP : http://www.jst.go.jp/keytech/h20-1besshi.html
[22] Project for Practical Application of Regenerative Medicine, Ministry of Education, Culture, Sports, Science and Technology HP : http://www.stemcellproject.mext.go.jp/gaiyo/index.html
[23] Collaboration with Kyoto University on Myocardiac Sheet Research using iPS Cells, Osaka University HP: http://handaiweb.com/mygate-588-0.html
[24] Next Generation Infection Vaccine Innovation Project, Documents from National Institute of Biomedical Innovation HP: http://www.nibio.go.jp/SuperTokku/Outline.html
[25] Partnership with Novocell Corporation in Researching Differentiation Induction from iPS Cells to Pancreatic CellsiPS, December 10, 2008, Kyoto University HP : http://www.kyoto-u.ac.jp/ja/news_data/h/h1/news7/2008/081210_1.htm
[26] CiRA and University of Toronto Sign Research Cooperation Memorandum, CiRA News Release, October 16, 2008 : http://www.icems.kyoto-u.ac.jp/cira/doc/081016_utoronto_J.pdf
[27] JST and CIRM Conclude on Research Cooperation Memorandum in Stem Cell Research, Japan Science and Technology Agency HP : http://www.jst.go.jp/pr/announce/20081118-2/index.html
[28] Patent Issued (Japan) on the Method to generate Artificial Pluripotent Stem Cells, CiRA News Release : http://www.icems.kyoto-u.ac.jp/cira/doc/080911_iPS_Patent_J.pdf
[29] Center for iPS Cell Research and Application (CiRA) HP : http://www.icems.kyoto-u.ac.jp/cira/j/cira_orga_stra.html
[30] JPMA News Letter, 126, 10-12 (2008) : http://www.meteo-intergate.com/news/letter/126/004.pdf
[31] Opinion on Pharmaceutical Industry Policy with a Central Focus on the Proposal of the 5-year strategy, Document by Japan Pharmaceutical Manufacturers Association, Welfare And Medical Service HP : http://www.wam.go.jp/wamappl/bb13GS40.nsf/0/040978efe06d50d64925749b0024aa98/$FILE/20080804_7shiryou2-2-1~2.pdf (Japanese)
[32] Document of Intellectual Property Strategy Meeting, Strategy on Intellectual Property Rights in Healthcare Industry, Office of the Prime Minister HP : http://www.kantei.go.jp/jp/singi/titeki2/dai21/siryou7.pdf
[33] Japan Pharmaceutical Manufacturers Association Supports Universities on Strategy on Intellectual Property Related to iPS Cell Research, Nikkei BP Corporation HP: http://chizai.nikkeibp.co.jp/chizai/etc/20081224.html
[34] Activity on Intellectual Property Support Project by JPMA,JPMA News Letter, 130, 6-8 (2009) : http://www.jpma-newsletter.net/PDF/2009_130_03.pdf
[35] iPS Academia Japan HP: http://ips-cell.net/index.php
[36] Policies Regarding Clinical Tests Using Human iPS Cells, July 3, 2006, Ministry of Health, Labor and Welfare, Ministry of Health, Labor and Welfare HP: http://www.mhlw.go.jp/bunya/kenkou/iryousaisei01/pdf/01.pdf

Profile

Yoshihiko SUMI
Affiliated Fellow,NISTEP
Frontier Bio Project Manager, Department of Research Project Promotion, New Business Development Group, Teijin Corporation
http://www.teijin.co.jp

Doctor of Medical Science
Dr. Sumi is currently working on research development and operation using biotechnology after doing research on the biochemistry of blood, regeneration of nerve cells and drug development. He strongly believes that Japan can lead the world with iPS cells research and that these cells can potentially overthrow the economic recession!

(Original Japanese version: published in March 2009)

2

Recycling Conducted by Material Industries: Current Conditions and Hindering Factors

Masao TAKEUCHI
Affiliated Fellow

1 Introduction

Only last year, the August 25, 2008, morning edition of the Nikkei reported that material and electronics companies would accelerate efforts to recycle used materials in response to the worldwide rise in resource prices. It is still fresh in our memories how rising material prices caused companies to begin emphasizing the use of recycled materials such as steel, aluminum, and paper and led to a rise in scrap prices and to an increase in imports and exports of scrap. However, the financial crisis that followed slowed down the world economy and changed the situation completely. For instance, the market price for steel scrap fluctuated erratically: the price per ton of steel scrap was almost 70,000 yen in July 2008, but by November 2008, it had plummeted to temporarily fall below the 10,000 yen mark.[1] Such drastic changes in material prices may devastate the commercial collection routes of paper, scrap, and other materials, and such changes are not favorable for maintaining a stable recycling system. Fortunately, however, the material industries continue to play a major role in commercial recycling, as will be discussed below. Recycling requires a number of steps: collection, sorting (including dismantlement), and the actual recycling. Various recycling laws are now in effect, and we are able to obtain relatively abundant information about the initial steps of collecting and sorting. However, it seems that little attention has been paid to the actual recycling step. This article discusses the recycling step.

Material industries use substantial amounts of materials recycled from waste, but, as it will be discussed below, the percentage of recycled materials in final products is not particularly high. For example, only about 24% of steel materials consist of scrap collected from the market, and the percentage has not changed very much.[2] Since little steel is lost during the recycling process, the amount of scrap is proportional to the accumulated amount of steel found in products in Japan. Therefore, if steel production continues steadily and the amount of steel in products accumulates, in the future it may be possible for scrap materials to feed most of the demand for steel despite small losses due to import/export or final disposal. However, there still seems to be a long way to before this stage is reached.

The demand for materials is rising in developing countries, but the supply is limited, thus, prices will inevitably rise in the long run. There will also be more cases where the supply for some materials, such as rare metals, will suppress production. Thus, for the economic advantages as well as for resource security, it is desirable that the portion of recycled materials in products increases and that imports of raw materials decrease. This article attempts to show the current state of material recycling by using some typical materials as examples, in order to understand why the ratio of recycled materials in products has not increased and to suggest directions for the future. There are many factors that hinder recycling, including economic trends, laws and regulations, and other social systems. However, many of these issues are beyond this author's expertise, and thus, I will mainly discuss the technological factors that hinder recycling.

Here, I would like to define some terms needed for the discussion below. Normally, when we discuss recycling, recycling rates (recycle ritsu [also saishigenka ritsu, saishohinka ritsu]) are often used. The recycling rate usually indicates the recycled quantity versus the quantity of waste. In case of home appliances, it is the ratio of the weight of parts or materials that were recycled versus the total weight of the original appliance. This definition is useful when we discuss the collection of waste or the reuse of parts. However, the definition is not very useful for the material industries because they use waste as materials, and the recycling rate can always be close to 100% if we only look at what comes out and goes into the factory. Therefore, this article uses the material recycling rate (also often referred to as the recycling rate) as an indicator of how much recycling is conducted in the material industries. The material recycling rate indicates the percentage (on average) of scrap or other recycled materials used in products.

Additionally, the Waste Disposal and Public Cleansing Act defines waste as undesired objects that carry no monetary value, and as such, scrap and other materials that the material industries accept are not, in that sense, waste if they carry monetary value. However, generally speaking, scrap is often called waste and may also be called different things by generators and acceptors of waste. Thus, this article calls objects that are no longer in use waste, waste products, or scrap. The Basic Act for Establishing a Sound Material-Cycle Society extended the definition of waste to include previously used objects and byproducts, among which useful items are considered recyclable resources. Therefore, I believe that it is acceptable to call things that have monetary value waste, if only in this article.

2 Characteristics of Recycling Conducted by the Material Industries

Some developing countries extensively reuse waste products, and Japan also used to do so during the Edo period (1603-1867)[3] and this trend continued to some extent until the period of high economic growth in the 1950's. However, this was not because there was a superior waste treatment system during the Edo period. Rather, reclaimed articles had sufficient commercial value due to relatively lower standards of living. As such, reuse of resources became widespread. Nevertheless, as the economy developed, Japan shifted to (and still is) a mass production and mass disposal economy. Recently, in response to the establishment of the Basic Act for Establishing a Sound Material-Cycle Society and various recycling laws, Japan finally began to strongly promote recycling. Surprisingly, however, it is not widely known that recycling of a wide variety of materials has been conducted to a large extent even within the mass production and mass disposal economy following the period of high economic growth.

Characteristics of recycling conducted by the material industries include the facts that recycling basically depends on market mechanisms, including collection routes, and that the quantity of recycled materials is substantial (there are cases where generators instead of acceptors of waste have to pay for recycling depending on the market). Such economic-based mass recycling is possible because, firstly, ferrous, nonferrous, and other metal scrap and used paper almost maintain their original state and their essential characteristics are unchanged after they are used in products (physical reason), and secondly, the recycling processes are almost the same as the normal production processes. The recycling processes for waste and the production processes using ores and other natural resources are said to be extremely similar.[4] That is to say:

Recycling:
Collection → separation → cleansing (refining) → shaping

Material production from raw materials:
Procurement → separation → cleansing (refining) → shaping

Each corresponding process is almost the same and only the collection and the procurement processes are different. Of course, each basic technology in each process has been improved for different raw materials, but the flow of the overall processes is extremely similar. Thus, by being able to accept a substantial amount of waste without having to alter the production processes, the material industries are able to control the increase in costs associated with changes in materials and to conduct economic-based recycling. The volume of recycled materials will be discussed later.

3 Recycling Laws and the Material Industries

PET bottles, aluminum cans, and paper are often consumed individually, and they can be easily recycled if they are not mixed with other materials.

Table 1 : Recycling of Four Types of Home Appliances (Fiscal 2007)

	Unit	Air Conditioners	TVs	Refrigerators	Washing Machines
Number of Appliances Collected at Designated Collection Centers	[Thousands]	1,890	4,613	2,725	2,884
Number of Appliances Treated (Recycling, etc.)	[Thousands]	1,872	4,542	2,724	2,879
Weight of Appliances Treated (Recycling, etc.)	[Tons]	78,715	134,283	159,763	94,101
Weight of Appliances Recycled	[Tons]	68,861	115,563	116,683	77,231
Recycling Rate	[%]	87	86	73	82

Prepared by the STFC based on Reference[5]

Table 2 : Recycling of Parts and Materials from Four Types of Home Appliances (Fiscal 2007)

	Unit	Air Conditioners	TVs	Refrigerators	Washing Machines
Steel	[Tons]	23,729	13,881	68,435	40,755
Copper	[Tons]	5,076	4,951	1,994	1,240
Aluminum	[Tons]	8,634	73	325	612
Mixed Materials of Nonferrous and Ferrous Metals, etc.	[Tons]	24,453	1,199	20,188	12,915
Glass from Cathode Ray Tubes	[Tons]	—	68,269	—	—
Plastic and Other Organic Materials *	[Tons]	6,969	27,190	25,741	21,709
Total Quantity	[Tons]	68,861	115,563	116,683	77,231

* Plastic and Other Organic Materials

Prepared by the STFC based on Reference[5]

For example, if we only remove a cap and a label (which are made from different materials) from a PET bottle, almost pure PET resin is left. However, in general, most waste is made out of several materials. Japan boasts large automobile and home appliance industries, but these products are assembled from parts, each made out of different materials. Therefore, disassembly is required between collection and sorting. Waste treatment businesses had been in charge of disassembling these products. However, various recycling laws (Act on the Promotion of Sorted Collection and Recycling of Containers and Packaging, Law for Recycling of Specified Kinds of Home Appliances, Act on Recycling, etc. of End-of-Life Vehicles, Law for the Recycling of Construction Materials, Law for the Promotion of the Utilization of Recyclable Food Resources) now require manufacturers to be responsible for disassembling certain products according to material.

In the case of waste home appliances (air conditioners, cathode ray tube televisions, refrigerators, and washing machines [clothes driers and flat-screen televisions were also included in April 2009]), some 48 recycling plants were working throughout Japan (as of 2007) to disassemble and sort these waste products in response to those recycling laws.[5] As Table 1 suggests, the number of waste products collected is substantial, and the recycling rates (saishohinka ritsu; same as saishigenka ritsu) are very high. However, targets are set for these recycling rates, and therefore, there are cases where recycling is conducted without regard for profits. Additionally, increases in illegal dumping, the treatment of used products in countries importing them, and other concerns have been expressed concerning the recycling laws. As Table 2 suggests, however, disassembly and separation under the recycling laws requires sorting by material, and thus works very well as a preprocessing step for recycling conducted by the materials industry.

4 Current State of and Factors Hindering Recycling Led by Material Industries

It will not be surprising if scrap materials can feed most of the demand in the future for ferrous and nonferrous metals and other materials whose quality does not change much during the recycling process. Realizing a higher material recycling rate is considered basically desirable because it should reduce imports and save energy. As discussed later, however, apart from the fact that the cumulative amount decreases via the import/export of products and scrap, the fraction of recycled waste in products must be limited in some cases for quality or technical reasons. In this part I use steel, aluminum, and paper, typical examples of material industries, to show the current state of recycling and what technical factors are preventing higher material recycling rates.

4-1 Current State of Steel Recycling

Figure 1 shows changes in the percentage of scrap from the market (as opposed to factory scrap) used in crude steel production and in materials.[2] It is clear what is in factory scrap, and therefore, it is often melted as-is for use or returned to shaft furnaces or converters. In fiscal 2006, total crude steel production was approximately 110 million tons, and the amount of scrap from the market was 26 million tons (about 24% compared to crude steel production), which was almost equal to the ratio of steel produced in electric furnaces to total steel production. Additionally, there are no clear statistics on the amount of scrap including factory scrap, but it is thought that it is over 50 million tons and the material recycling rate (including factory scrap) is about 45%. Since it is clear what is in factory scrap, it should be easy to recycle. Therefore, when promoting recycling, it is more important to improve the recycling rate for scrap from the market. Incidentally, waste generation in Japan is more closely related to the amount of steel used, or the cumulative amount of steel, than crude steel production. Some 2 to 3% of the amount of steel used in Japan is said to become waste. Currently, the cumulative amount of steel is more than 1.3 billion tons, of which about 2% becomes waste. As such, the waste generation rate is gradually declining.

4-2 Factors Hindering Steel Recycling

There are two different ways to make steel: one is to have ore, limestone, and other raw materials treated in shaft furnaces and converters; and the other is to mainly have scrap treated in electric furnaces. Waste products from the market are mostly treated in the latter way. Steel produced in shaft furnaces and converters is used mainly for high-quality products that have strict requirements as to their components, such as thin and thick plates for cars. Some scrap is used for these kinds of products, but they are mostly made from ore. In contrast, most steel produced in electric furnaces is used for small steel bars and steel wires for construction that have high component tolerances. Since strict component control is not needed for these products, the required performance can be obtained from properly separated scrap. Using scrap and raw materials for different purposes is also commonly seen in the production of other materials such as nonferrous metals like aluminum and paper. This is sometimes called cascade recycling.

Scrap from the market is not used for production in shaft furnaces and converters because it contains small amounts of elements that are hard to separate (called tramp elements) and which remain in products. For example, scrap from the market includes copper from electric wires, etc. from old products, but a higher density of copper makes products crack easily at the time of processing. As such, the amount of copper in steel products is strictly limited. Table 3 indicates the tolerance limits for copper in steel products.[6] The current steel making method using shaft furnaces and converters cannot separate copper from iron. Thus, the amount of scrap from the market that is put into shaft furnaces and converters has to be kept low. To solve the issue, it is necessary to develop technology to eliminate copper and other tramp elements during production and technology to eliminate tramp elements from scrap.

Another tramp element issue is that rare metals (such as manganese, chrome, molybdenum, and niobium) used as alloy constituents for high-strength steel and other products cannot be collected, and thus, these valuable resources become slag and are lost[7]. Currently, it is difficult to separate and collect elements that are present in small amounts through the sorting and refining processes. It will be necessary to find a way to sort and recycle materials containing many alloy constituents (in other words, high-quality

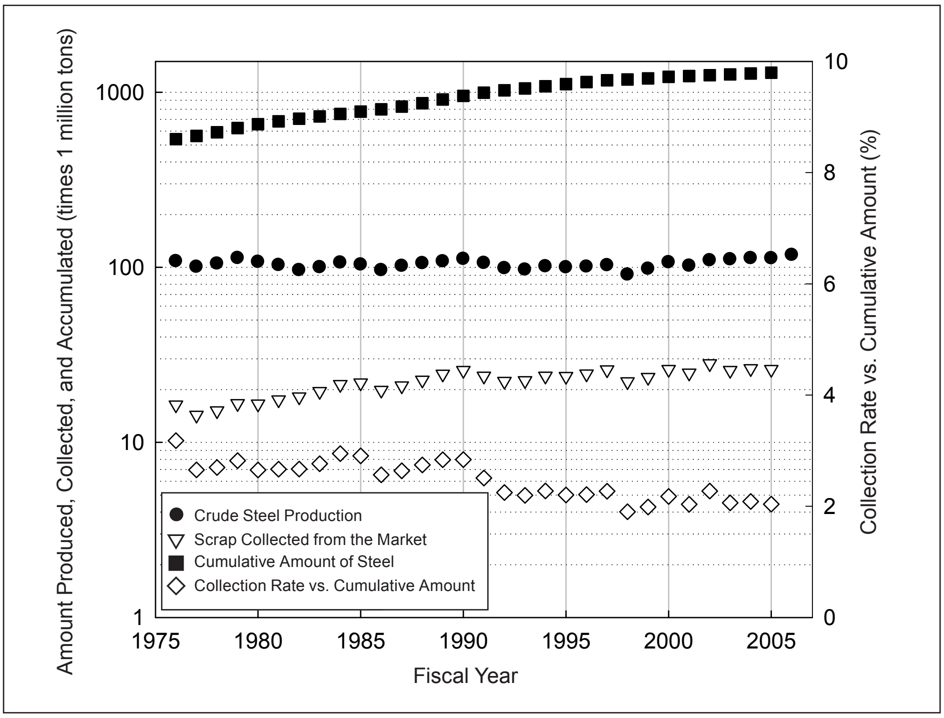


Figure 1 : Steel Production and Recycling

Prepared by the STFC based on Reference[2]

Table 3 : Copper Tolerance in Steel Products

Steel Product Grade	Tolerance Limit	Actual Value	Product	
	Copper (%)	Copper (%)	1 Million Tons	Production Method
・Deep-Drawing Steel Sheet/ High-Quality Thin Steel Sheet ・Steel Sheet for Tinplate/ Surface Treated Steel	≦ 0.06 ≦ 0.06	0.02~0.03	34.3	Mainly Shaft Furnace
Hot-Rolled Steel Sheet/ Medium-Thick to Thick Plate,Steel Pipe	≦ 0.10		25.3	
Cold-Rolled Thin Steel Sheet/ Thin Sheet in General	≦ 0.10			
Shaped Steel/Rolled Steel Product for Machine Structure	≦ 0.30	0.20~0.35	23.7	Mainly Electric Furnace
Shaped Steel/Rolled Steel Product for Machine Structure	≦ 0.40	0.25~0.50	16.8	
Special Steel	0.35/0.40	0.08~0.13	—	

Prepared by the STFC based on Reference[6]

steel products) when we generate scrap. The domestic demand is shifting toward high-quality steel products, and thus, solving the issues concerning tramp elements will become more important.

4-3 Recycling of Aluminum

Production of aluminum from bauxite and other types of ore requires substantial amounts of electricity. In contrast, the energy needed for recycling aluminum is only about 3% of that needed for producing aluminum. As such, the significance of recycling aluminum is very high. Because electricity is expensive in Japan, only small amounts of aluminum are domestically produced from ore. Most aluminum products produced in Japan are made from imported metals and scrap. There is no quantitative data on the

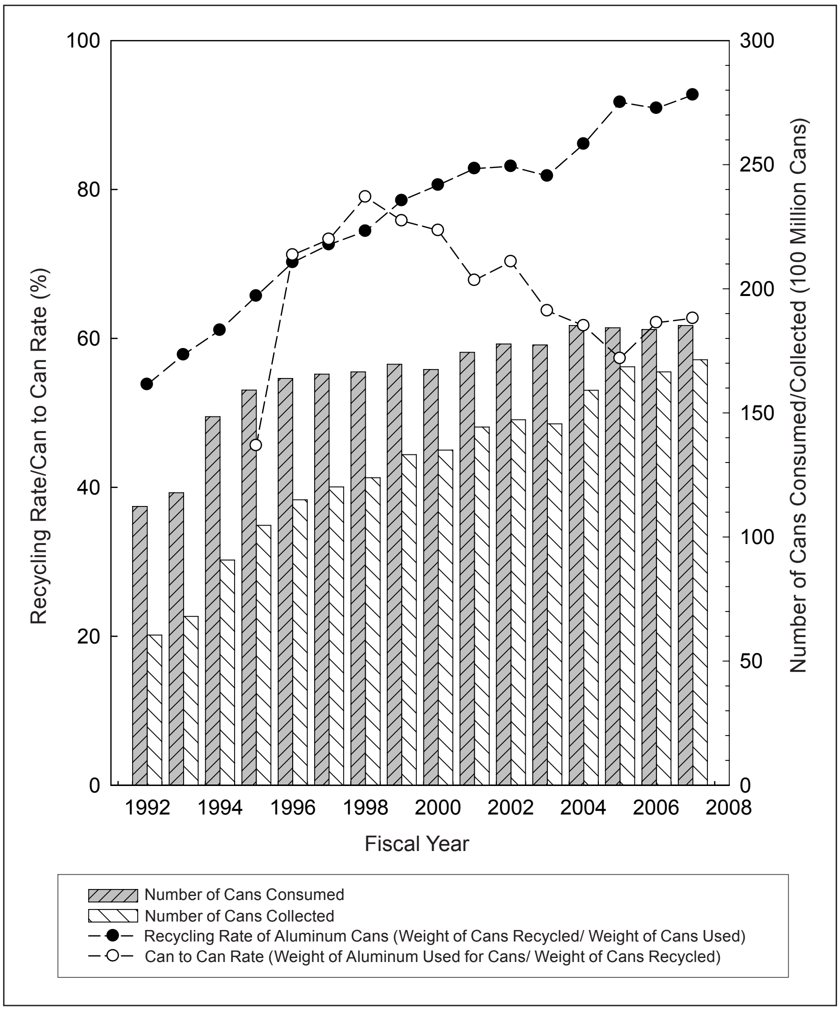


Figure 2：Steel Production and Recycling

Prepared by the STFC based on Reference[9]

material recycling rate of aluminum, but, based on the material flow analysis[8] conducted by the Japan Oil, Gas and Metals National Corporation (JOGMEC), the rate is estimated to be approximately 28% (alloy produced from scrap was 1.189 million tons and the total domestic demand was 4.229 million tons according to the 2006 data). The rate is surprisingly low for a material that is easy to recycle and for which the advantages of recycling are great.

In contrast, according to the data on the recycling of aluminum cans[9] shown in Figure 2, the recycling rate is very high, at more than 90%. This is probably because municipal governments and companies conduct thorough collection and sorting. The data also suggests that the material recycling rate for general aluminum scrap can be very high if collection and sorting are conducted properly.

4-4 Factors Hindering the Recycling of Aluminum

Aluminum production can be divided into two types: production of rolled products, such as mold materials to be used for sheets and sashes; and production of aluminum alloy, the constituents of which are adjusted for use in die casts and the like. Like steel, the cascade recycling process is common for aluminum. Imported metals and factory scrap (and used cans, etc.) are mainly used for rolled products, which have strict requirements for performance. Scrap is mainly used for aluminum alloy. A large fraction of aluminum sashes become scrap, and these sashes contain magnesium. The amount of magnesium in the sashes can exceed the tolerance rate for die cast alloy, and thus, the amount needs to be adjusted. Normally, it is difficult to adjust the amount of magnesium only by sorting and combining scrap containing different constituents. Therefore, taking advantage of the fact that chlorine reacts more quickly with magnesium than with aluminum, chlorine gas is blown into melted aluminum, or chlorine-based flux is used, to isolate magnesium in the form of magnesium chloride. Unlike the case of steel, a technique to separate a tramp element in aluminum alloy, namely magnesium, has been established. However, the use of chlorine generates dioxins, creating another issue. Furthermore, in addition to magnesium, there are other minor constituents in scrap, and therefore, it is essential to develop further techniques to, for example, remove other minor constituents in order to produce high-purity aluminum products from scrap.

Recently, the use of high-quality aluminum products (containing alloy constituents made from rare metals) has been increasing in cars and other products. If these aluminum products are melted as-is (as alloy materials), these rare metals are lost, creating issues similar to those with steel. It is also essential to find a way to sort aluminum products when they are disassembled and to recycle high-performance products using a different route.

4-5 Recycling of Other Nonferrous Metals

In addition to aluminum, recycling of other nonferrous metals is also being actively conducted and I would like to discuss it briefly. The material recycling rates were calculated based on JOGMEC data[8].

1) Copper

Unlike aluminum, constituents are not adjusted when making copper alloy. Thus, electric wires, bronze, and brass are individually melted for the next use. The material recycling rate is approximately 28% (scrap: 768,000 tons; products: 2.748 million tons; 2006). Printed circuit boards, wires in home appliances, and other products used in small units are difficult to recycle. This issue is common to any kind of material.

2) Lead

Lead is mostly used for batteries. The material recycling rate is relatively high at around 33% (lead scrap: 83,000 tons; metal production: 255,000 tons; 2006). Tubular lamp glass for cathode ray tubes contains a high level of lead but is recycled as glass and is not included in the calculation here. Liquid crystal televisions have become very popular and the demand for cathode ray tubes has been dropping rapidly. As such, it will be difficult to recycle tubular lamp glass for the same use. Therefore, it is essential to find a way to separate lead from glass or to use it in another way.

3) Zinc

Zinc is mostly used for coating and is mainly recycled from exhaust from electric furnaces for steel. The material recycling rate is about 16% (scrap, etc.: 108,000 tons; metals: 655,000 tons; 2006). Brass contains zinc, but it is often melted together, and as such, zinc in brass is not included in the calculation here.

4) Rare Metals

Recycling of rare metals from cell phones and information devices has also been actively conducted. Looking at worldwide recycling of metals from circuit boards, etc., reveals that only precious metals such as gold and platinum are recycled. However, Japanese companies have inherited techniques to refine ore containing complicated constituents, such as black ore, and now have techniques to recycle not only those precious metals but also other rare metals. Rare metal mines are located only in a few countries. As such, considering resource security, it will be necessary to promote rare metal production through recycling. As discussed earlier, it will be essential to develop techniques to collect rare metals not only from products like cell phones but also from materials containing different constituents, such as steel and aluminum.

4-6 Recycling of Paper

Figure 3 shows the state of paper recycling.10] Pulp, the main constituent of paper, cannot be recycled into high-quality paper when the fiber becomes short. As such, unlike metals, paper can only be recycled a number of times. Therefore, paper recycling needs to be looked at differently. The material recycling rate (percentage of recycled pulp content in paper) has been gradually increasing, and it is now more than 60%. The industry is aiming to achieve 62% in 2010. Considering the necessity to supplement worn pulp, this rate is very high and is approaching the limit under the current circumstances. However, looking at different types of paper, the rate varies considerably: 93% for cardboard, 75% for newspaper, and 53% for paper for sanitary use. The average of the rates excluding the rate for cardboard is 38%.

4-7 Factors Hindering Paper Recycling

The chemical pulp production process in papermaking mainly aims to, by using chemicals, remove lignin, which acts as glue to hold pulp together in wood. The mixed substance of removed lignin and the chemicals is called black liquor. Black liquor is

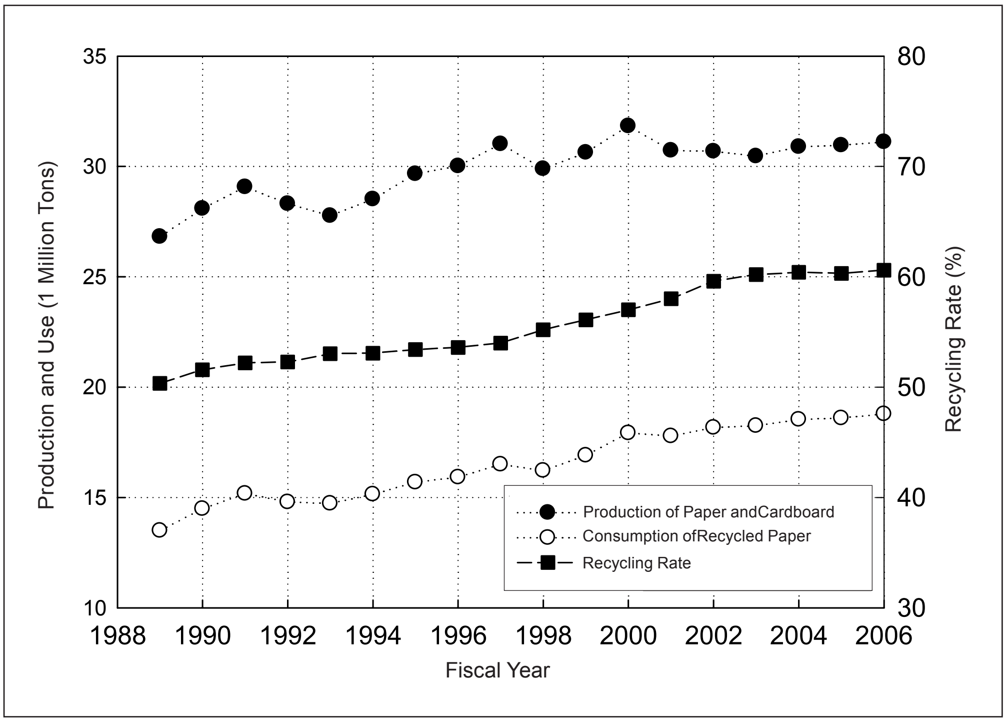


Figure 3：Changes in Paper Recycling

Prepared by the STFC based on Reference[10]

burned in order to be recycled, as well as to generate electricity and to use the steam. Shortened fiber pulp and unnecessary inflammables in used paper can be used as energy, but the total quantity of black liquor decreases. Therefore, as the material recycling rate increases, the consumption of fossil fuel also increases. The paper industry has been conducting efforts to reduce the consumption of fossil fuel by, for example, improving the processes and increasing the use of biomass. However, considering the issue of energy supply and the necessity of supplementing worn pulp, it is not necessarily rational to ask for 100% recycled paper. This is definitely different from the recycling of metals. What is similar to the recycling of metal scrap is that impurities mixed into collected waste paper become an obstacle to recycling. Additionally, used paper containing short fiber pulp and impurities is recycled into cardboard, which has low quality requirements. As such, it is close to cascade recycling.

Limits to improving the material recycling rate in paper pulp have depended mainly on the decreased strength of recycled paper due to deteriorated pulp fiber. Recently, however, demand for paper has been increasing in emerging countries, and Japanese paper manufacturers now have to use low-quality waste paper. Impure substances that are difficult to remove (such as ink, adhesives, printed materials containing UV ink, colored paper, carbon paper, and non-carbon paper) are the cause of lower material recycling rates. Since the recycling of cardboard has almost reached its limit, in order to enhance the material recycling rate further, it is essential to eliminate impurities (including when collecting waste paper) as well as to improve technology to remove impurities during the papermaking process[11] Separating copy paper and print paper containing small impurities from magazines, packages, and other miscellaneous paper will further lead to the improvement of the material recycling rate. These efforts are already being conducted to some extent.

4-8 The Contribution of Recycling to the Environment

Recycling enables us to use the same materials again and again, ultimately reducing the amount of waste to be disposed of. At the same time, the use of recycled materials (domestic resources) can reduce imports of materials as well as the amount of energy required for production. When one considers the other advantages of recycling, such as reducing adverse environmental impact in countries producing resources and reducing the energy used for long-distance transportation, it is apparent that the use of recycled materials should be increased.

Furthermore, due to the high production capacity

Table 4 : Waste Materials Used in Cement Production

Item	Use	2003	2004	2005	2006	2007
Blast Furnace Slag	Raw Material, Admixture Material	10173	9231	9214	9711	9304
Coal Ash	Raw Material, Admixture Material	6429	6937	7185	6995	7256
Sewage, Sludge	Raw Material	2413	2649	2526	2965	3175
Waste Soil from Construction	Raw Material	629	1692	2097	2589	2643
By-Product Gypsum	Raw Material (Ad-in Material)	2530	2572	2707	2787	2636
Cinder (Excluding Coal Ash), Soot, Dust	Raw Material, Thermal Energy	953	1110	1189	982	1173
Nonferrous Slag, etc.	Raw Material	1143	1305	1318	1098	1028
Casting Sand	Raw Material	565	607	601	650	610
Steel Mfg. Slag	Raw Material	577	465	467	633	549
Waste Plastic	Thermal Energy	255	283	302	365	408
Wood Chips	Raw Material, Thermal Energy	271	305	340	372	319
Recycled Oil	Thermal Energy	238	236	228	249	279
Waste Oil	Thermal Energy	173	214	219	225	200
Waste White Clay	Raw Material, Thermal Energy	97	116	173	213	200
Bota	Raw Material, Thermal Energy	390	297	280	203	155
Waste Tires	Raw Material, Thermal Energy	230	221	194	163	148
Meat and Bone Powder	Raw Material, Thermal Energy	122	90	85	74	71
Others		378	452	468	615	565
Total		27564	28780	29593	30890	30720
Amount of Use per ton of Cement (kg/t)			401	400	423	436

Note 1: "Others" includes waste acid, waste alkali, waste paper, waste glass and ceramic, concrete and brick fragments, RDF, etc.
Note 2: "Amount of Use per ton of Cement" indicates amounts of wastes and by-products used as materials,thermal energy sources, or admixture materials in order to produce one ton of cement.

Prepared by the STFC based on Reference[12]

per factory, the material industries (which play a leading role in the latter steps of recycling) can often conduct very effective waste treatment by using only small fractions of materials from different waste products as part of materials or fuel. For example, steel manufactures accept substantial amounts of waste plastic products and feed them into shaft furnaces or use them after restoring chemical substances in coke furnaces, contributing to reducing the use of coal. In addition, aluminum alloy manufacturers are the largest users of restored fuel oil such as lubricating oil, and the paper industry has introduced solid fuel (RPF) derived from waste plastic products. Therefore, the material industries can make various contributions to the environment.

Table 4 shows the use of waste by the cement industry, one of the material industries.[12] Cement production basically does not produce waste, and most waste brought in from outside is used as materials or fuel. The amount of such waste is quite substantial. Without the cement industry, industrial wastes, especially the ones that are toxic and difficult to be disposed of, could not be treated. Other material industries are also expected, taking advantage of their own characteristics, to develop technologies that contribute to treating waste unrelated to their own products and to ultimately improve a business culture that is now easily affected by the market.

5 Further Promotion of Material Recycling

The material industries are already using substantial amounts of recycled materials on a commercial basis. Thus, to further improve the material recycling rates, considerable effort will be required. From a long-term perspective, it is very beneficial to promote recycling for the conservation of the environment and energy. However, simply aiming to increase the resource recycling rate might lead to higher production costs and lower product competitiveness, higher energy consumption, or loss of valuable rare metals.

Material recycling can be divided into a number of subtypes: upgrade recycling where high-grade material is reproduced from recycled material; closed-loop recycling where mostly the same material is collected for recycling (for example, cans to cans); and cascade recycling where waste products are only recycled into low performance materials.[4] Upgrade recycling is usually difficult to do for technical and economic reasons. Therefore, as discussed in Chapter 4, cascade recycling is common. However, there is an increasing demand for high-quality materials, creating a mismatch between supply and demand. This may eventually cause material recycling rates to stop improving. While it may be difficult to achieve soon, from a long-term perspective, it is necessary to create a system where closed-loop recycling for high-grade materials is also common, as well as to develop technology to make upgrade recycling possible to some extent. The market will probably determine the optimal fractions of closed-loop, upgrade, and cascade recycling. However, scrap materials and products also depend on the market, and thus, it will be necessary for administrative bodies to guide the direction to a certain extent. Furthermore, it is essential to create a social system and develop technology to flexibly respond to the constantly changing market. Creating a legal framework (similar to the recycling laws) will be needed, especially for the development of a social system.

I would now like to point out some technological issues regarding the future development of material recycling, including the technological conditions that hinder recycling as suggested above.

1) Necessity of Developing Technology to Improve Material Recycling Rates

As discussed in the previous chapter, upgrade recycling (where high-grade materials are produced from recycled materials) faces many obstacles in terms of technological development. In the case of steel, it will be necessary to develop technology to remove tramp elements such as copper from scrap, to develop an iron making method that includes a process to separate tramp elements, and to develop technology to produce high-quality products even with tramp elements. The circumstances are very similar for nonferrous metals and paper. Research and development is needed for sorting and production technology. Sorting technology will be discussed in 2) below, but the development of low technology tends to be emphasized because it costs less and is easy to work on. Therefore, funding is essential to nurture new ideas for sorting technology at universities and public research institutions. The development of production technology should be basically conducted by companies, but administrative bodies also need to be involved in setting goals to encourage those activities.

2) Necessity of Developing Products That are Easily Recycled

The recycling laws target products that are assembled or are made from different materials. As such, steps such as disassembly, sorting, and separation are required. Normally, after products are disassembled, they are roughly sorted by material, and crushed and separated. High-quality materials are returned to the material industries for recycling and the rest is permanently disposed of. Many companies have begun efforts to design their products to be easily disassembled and separated.[13,14] The greatest advantage of adopting extended producer responsibility (EPR) into the recycling laws is that producers are led to develop products that can be easily treated after they become waste. It is the private sector that can play a role in developing such products, but there is a gap in awareness even among companies in the same industry. Therefore, progress made by pioneering companies should be shared and goals should be established through the initiative of the public sector.

New ideas for technology for use in disassembly and separation have emerged. For example, the following technologies have been proposed: the wearing of power suits (an application of robotics) to remove wire harnesses from cars; technology that uses shape-memory alloy to hold parts together and permits quick disassembly by heating them; and technology to put a decomposition catalyst in plastic and liquefy plastic through heating to remove it. Some proposals are close to practical implementation. It depends on how good such ideas are to some extent, but it is essential to improve the system to evaluate and nurture these kinds of proposals made at research institutions and venture companies so that new ideas for technology will not be lost.

3) Necessity of Technology to Make Sorting after Disassembly Easy

To make closed-loop recycling common, it is expected that there will be cases where materials need to be assessed after dissolution or disassembly. In the case of industrial waste, a control manifest for industrial waste indicating its contents is attached. However, the information is not sufficient for sorting materials. There are also cases where manifests are not attached if the waste is not industrial or has monetary value and is bought by a waste collecting business. It is essential to be able to assess materials accurately in order to further develop recycling. There may be different solutions, but if different components are marked or IC-tagged with necessary information about their materials, it will be remarkably easier to sort them. Considering how global the distribution of goods is, it is essential to try to make such an information system a global standard. Thus, the public and the private sectors need to work together. IC tags for waste treatment are already being tried and tested. However, they only substitute for manifests, or their use is limited to tracking at the time of transport. It will be necessary for industry and academia to work together to consider applying them to sorting and verifying the effects.

6 Conclusion

Aside from dissipation or disappearance during collecting or recycling processes or import/export, treatment efficiency in each recycling process has its limit. Therefore, not only paper, but also steel and nonferrous metals naturally have limits in terms of material recycling rates. However, the current material recycling rates have been kept lower than their limits due to various hindering factors other than treatment efficiency. In the long term, it would be very beneficial to promote recycling further for the conservation of both the environment and energy. As such, it is essential to improve material recycling rates even through small efforts. Currently, there are many issues to be solved. Looking at recycling conducted by the material industries, for example, there are issues concerning tramp elements, losses of rare metals, and the mismatch between supply and demand due to increasing demands for high-quality materials. To suggest a direction for solving these issues, this article pointed out the necessity to: establish a system where closed-loop recycling is common, like cascade recycling; develop technology to conduct more upgrade recycling; develop products easily disassembled for recycling; and develop technology to support recycling. Recycling involves waste generators, industries conducting collection and disassembly, and users of recycled materials. Therefore, the material industries cannot determine a long-term strategy by themselves. It will be essential for industries, academia, and governments to work together with each playing its own role to conduct research and development. Administrative bodies, residents, and industry also need to continuously discuss how recycling should be conducted and do what they can. It is also essential for governments to lead the private sector toward long-term goals.

References

[1] Japan Ferrous Raw Material Association: Ferrous Steel Market Trends (Weekly)：http://www.tetsugen.gol.com/saishin/3index1.htm

[2] Japan Ferrous Raw Material Association: Supply and Demand StatisticsProduction：http://www.tetsugen.gol.com/kiso/1seisan.htm
Accumulated Quantity Estimation of Japan：http://www.tetsugen.gol.com/kiso/5chikujapan.htm

[3] Mitsuo Nezaki: Kankyo Toshi no Shinjitu (Truth about the Eco-Friendly City), 74, Kodansha (2009)

[4] Takashi Nakamura: System and Technologies for Metals Recycling, Journal of the Japan Institute of Energy, Vol.87, No.4, 242 (2008)

[5] Association for Electric Home Appliances, Recycling of Electric Home Appliances Annual Report, 2007：http://www.aeha.or.jp/02/pdf/kadennenji19.pdf

[6] Seiichi Hayashi: Increasing Significance of Steel Scrap, Japan Technical Information Service, 115 (2005)

[7] Kazuyo Yokoyama, Kenichi Nakajima, Shinichiro Nakamura, Tetsuya Nagasaka: Material Flow Analysis on Steel Recycling Considering Accompanying Substances, Journal of the Japan Institute of Energy, Vol.87, No.4, 247-253 (2008)
[8] JOGMEC Virtual Mineral Resources Information Center, 2007 Study Report on Mineral Resource Material Flows：http://www.jogmec.go.jp/mric_web/jouhou/material_flow_frame.html
[9] Japan Aluminum Can Recycling Association: http://www.alumi-can.or.jp/data/recycle_graph.pdf
[10] Paper Recycling Promotion Center, Paper Recycling Statistics Graph (2007)：http://www.prpc.or.jp/statistics/zuhyo-koshi2007.pdf
[11] Mitsuhiro Sugino: The Current Situation and Problems of Paper Recycling, Journal of the Japan Institute of Energy, Vol.87, No.4, 261(2008)
[12] Japan Cement Association, Environmental Efforts in the Cement Industry, Changes in Use of Waste and Byproducts：http://www.jcassoc.or.jp/cement/1jpn/jg2.html
[13] Kazuya Shishido: Automobile Design for Recycling, Journal of the Japan Society of Mechanical Engineers, Vol.109, No.1055, 837 (2006)
[14] Kiyoshi Ueno: Recycle Oriented Design for Home Electric Appliances, Journal of the Japan Society of Mechanical Engineers, Vol.109, No.1055, 842 (2006)

Profile

Masao TAKEUCHI
Affiliated Fellow,NISTEP
Group Leader, Combustion Control Group, Energy Technology Research Institute, National Institute of Advanced Industrial Science and Technology

His major research interest is combustion engineering. He has studied combustion treatment of waste materials, and production and control of dioxin and other materials from combustion, and his research covers environmental engineering. He is also very interested in recycling and energy conservation.

(Original Japanese version: published in Febrary 2009)

3

World Research Trends in Child Health and the Environment

Hiroshi NITTA
Affiliated Fellow

1 Introduction

It has been reported worldwide that health problems caused by environmental pollution disproportionately affect unborn babies and small children. It is also known that children go through some developmental phases that are highly sensitive to certain pollutants. When unborn and small children go through physical and mental development, different organs develop at different times, and as such, some organs are more sensitive than others to certain materials during certain developmental phases. In addition, some researchers support the so-called Barker hypothesis, which suggests that low nutritional conditions before birth result in lifestyle-related diseases later as adults. Moreover, despite the improvement of medical care and welfare, it is thought that the incidence and prevalence rates of some health conditions such as allergies are higher among the current generation than previous ones.

Furthermore, children are more passive than adults when it comes to exposure to environmental pollutants. Children's characteristic behaviors, higher food intake per weight compared to adults, and their distinctive metabolism of environmental pollutants, mean that children typically suffer greater exposure to environmental pollutants than adults.

In recent years, there has been growing worldwide concern over children's vulnerability to environmental changes, and studies have been conducted in the United States and elsewhere to understand the relationship between the environment and child health, to find ways to protect children's health, and to use the findings for disease prevention and treatment. This article introduces worldwide trends in these studies, particularly studies in the United States, which are conducted at the largest scale, to suggest future directions of study for Japan.

2 Background

That the influence of environmental pollution on children should be more seriously considered was clearly acknowledged internationally for the first time in the 1997 Declaration of the Environment Leaders of the Eight on Children's Environmental Health. The declaration gave the protection of children's environmental health the highest priority among environmental issues, and it was agreed that, within the jurisdiction of each minister, research on the relationship between child health and the environment should be promoted and that the findings should be reflected in risk assessments and standard-setting.

In the United States, the National Academy of Sciences reported in 1993 on the health risks of dietary exposure of infants and children to pesticides in "Pesticides in the Diets of Infants and Children" and proposed that children's vulnerability should be taken seriously. In response to the report, the Environmental Protection Agency announced new policies in 1995, taking into consideration health risks to children. Additionally, the Food Quality Protection Act of 1996 was passed, requiring the Environmental Protection Agency to take into account children's vulnerability when setting safety standards for pesticides and residual contaminants. In 1997, President Clinton signed the Executive Order on the Protection of Children from Environmental Health Risks and Safety Risks and established a task force concerning environmental protection and safety for children. The Environmental Protection Agency and the National Institute of Environmental Health Sciences launched a research project on children's environmental health and disease prevention. This effort eventually led to

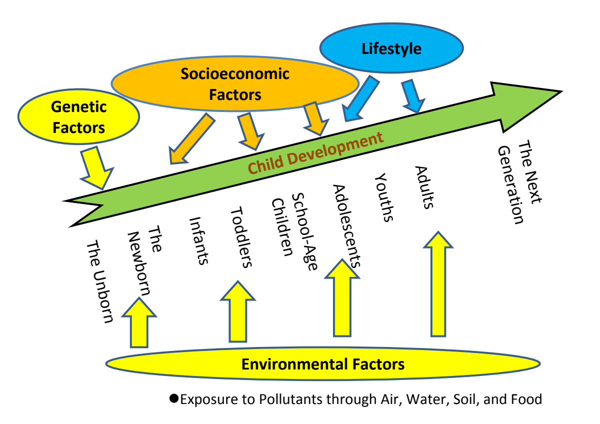


Figure 1 : Child Development and Environmental and Other Factors

Prepared by the STFC based on Reference[3]

the National Children's Study as discussed below. In addition, it required that environmental standards in the United States clearly show consideration for risks that are particular to children. As a result, risk assessments for children are now included in every document providing a scientific basis for setting environmental standards.

In Europe, an environmental policy for the protection of children's health was established at the Third Ministerial Conference on Environment and Health in 1999. At the Fourth Ministerial Conference on Environment and Health in 2004, the Children's Environment and Health Action Plan for Europe was adopted and the member countries committed themselves to developing and implementing national environment and health action plans for children by 2007. In response to these developments, Denmark and Norway began national epidemiological research projects on child health.

In Japan, the Ministry of Environment established a study panel on children's environmental health in 2005 and has been examining the issues and studying overseas research trends. The ministry is planning to begin a national study in 2010, and it launched a pilot study in 2008.

Cohort studies, which follow the same subjects for a long period of time, are being planned in countries around the world since they are the most suitable method for finding the causes of diseases in epidemiological research. It is particularly necessary to conduct continuous studies when evaluating effects on children at every developmental phase from before birth until adulthood. Many large studies of adult health have been conducted worldwide with the aim of finding and preventing lifestyle diseases and the risk factors for cancer. One characteristic of research on child health is that children's relationship with the environment changes as they pass through different developmental phases from before to after birth. In other words, children's susceptibility to environmental changes differs depending on their developmental phase. Susceptibility is also known to vary according to the different structures and functions of organs. Thus, the importance of conducting cohort studies through different developmental phases is more significant than with adults. Furthermore, these studies have been planned and implemented in different countries because independent research is considered necessary due to the close relationship between child development and genetic, socioeconomic, and cultural factors (Figure 1).

3 Large Epidemiological Studies in the United States

Among studies that are currently being planned or implemented worldwide, the National Children's Study in the United States is the largest. The Child Health Act, passed in 2000, authorized the National Institute of Child Health and Human Development to carry out a nationwide study. The start of full-fledged studies was delayed due to the changing administration and difficulty in acquiring sufficient funding. However, the implementation of pilot studies, research planning, selection of research areas and research implementation organizations, and other preparations were completed. The full-fledged studies officially began in January 2009.

3-1 Characteristics of the National Children's Study

The National Children's Study provides a model for a national research project targeting a great number of people. Using epidemiological terminology, the study can be termed a positive cohort study. However, the study goes far beyond the framework of epidemiological studies in medical science, especially in social medicine. It takes into account every factor of people's everyday life and the environment and attempts to clarify the relationship between these factors and the growth, health, and safety of unborn babies and children. The environment that the National Children's Study covers is not only limited to physical and chemical environments but includes a wide range of factors such as genetic and socioeconomic factors and lifestyles. However, it is not possible to study the relationship between these numerous factors and every effect on health that can be caused by these factors. Therefore, more than 100 research hypotheses were examined during the planning stage, and as a result, the following core hypothesis topics have been established (Figure 2). The core study hypotheses were examined and proposed by working groups established by a federal advisory group. The topics of the core hypotheses can be roughly divided into pregnancy, birth, reproduction, children's physical and mental development, asthma, obesity, disabilities, their relationship to exposure to environmental pollutants and social factors such as family and neighborhood characteristics, and also the correlation between these factors and genetic factors. In other words, the National Children's Study covers a wide range of study topics involving different agencies and departments, and as such, the study is not conducted by a single organization. (Within the Japanese government, examples of such organizations include the Ministry of Environment, the Ministry of Health, Labour and Welfare, or the Ministry of Education, Culture, Sports, Science and Technology.) The study, which is about to be fully implemented, does not stand out from other large cohort studies when we look at the target population of 100,000 or the length of the study (more than 20 years). However, considering that new legislation was passed to support the study, it is truly a national project.

[Pregnancy Outcomes]
1. Birth defects from impaired glucose metabolism
2. Increased risk of preterm birth from intrauterine exposure to mediators of inflammation
3. Increased risk of fetal growth restriction, preterm birth, birth defects, and developmental disabilities in children born through assisted reproductive technologies
4. Maternal subclinical hypothyroidism and neurodevelopmental disabilities/adverse pregnancy outcomes

[Neurodevelopment and Behavior]
5. Non-persistent pesticides and poor neurobehavioral and cognitive skills
6. Prenatal infection and neurodevelopmental disabilities
7. Gene-environment interactions and behavior
8. Prenatal and perinatal infection and schizophrenia

[Child Health and Development]
9. Family influences on child health and development
10. Impact of neighborhood and communities on child health
11. Impact of media exposure on child health and development
12. Social institutions and child health and development
13. Influences on healthy development

[Asthma]
14. The role of prenatal maternal stress and genetics in childhood asthma
15. Exposure to indoor and outdoor air pollution, aeroallergens, and asthma risk
16. Dietary antioxidants and asthma risk
17. Social environmental influences on asthma disparities
18. Early exposure to structural components and products of microorganisms decreases the risk of asthma
19. Environmental exposures interact with genes to increase the risk of asthma and wheezing in children

[Obesity and Growth]
20. Obesity and insulin resistance from impaired maternal glucose metabolism
21. Obesity and insulin resistance from intrauterine growth restriction
22. Breastfeeding associated with lower rates of obesity and lower risk of insulin resistance
23. Fiber, whole grains, high glycemic index and obesity and insulin resistance
24. Genetics, environmental exposures, and Type I diabetes

[Injury]
25. Repeated mild traumatic brain injury and neurocognitive development
26. Behavioral exposures, genetics, and childhood or adolescent onset aggression
27. Antecedents and resiliency to traumatic life events in childhood

[Reproductive Development]
28. Hormonally active environmental agents and reproductive development

Figure 2 : Core Hypothesis Topics of the National Children's Study

Prepared by the STFC based on Reference[2]

3-2 Organization and Funding of the National Children's Study

As shown in Figure 3, the National Children's Study is mainly administered by the National Institute of Child Health and Human Development, which is a subordinate institute of the National Institutes of Health (NIH). Additionally, an interagency coordinating committee (comprised of the National Institute of Environmental Health Sciences [another subordinate institute of NIH], the Environmental Protection Agency, and the Centers for Disease Control and Prevention) coordinates interagency cooperation systems and policy issues. The Program Office is the main body responsible for implementing the National Children's Study and is located in a suburb of Washington, D.C. Some 23 full-time staff members from epidemiology, medicine, statistics, sociology, and other disciplines of study are allocated among the following divisions: general affairs/accounting, protocol planning, environmental measurement, analysis/sample maintenance, information technology, data management/security, and public relations/regional coordination. In addition, the Coordinating Center (a private contractor) provides day-to-day coordination and support services. The Coordinating Center is also staffed with specialists (whose specialties correspond to those of the specialists at the Program Office) and their assistants, providing services including coordination among the Study/Vanguard Centers around the United States.

The National Children's Study aims to follow approximately 100,000 children and has chosen 105 study locations to represent the whole country by employing a multistage-clustered probability sampling approach. The study will ask women of childbearing age in specified neighborhoods at each

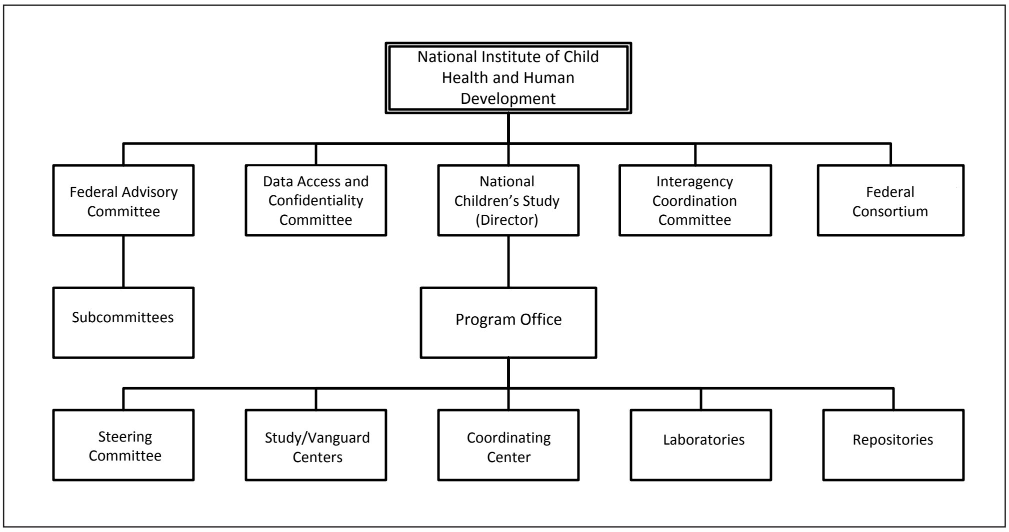


Figure 3 : National Children's Study Organization Chart

Prepared by the STFC

Table 1 : Changes in Funding for the National Children's Study (Dollars in Millions)

	Funding received during the planning phas							Funding received during the implementation phase	
Fiscal Year	2000	2001	2002	2003	2004	2005	2006	2007	2008
Funding amount	1.0	3.2	6.1	10.6	10.6	11.0	12.1	69.0	110.9

Prepared by the STFC

Table 2 : Summary of National Children's Study Questions

Questionnaire (mother, father)		Family structure, demographic variables, health conditions, medical history, income, diet, lifestyles, housing characteristics, pets, use of home appliances, occupations, hobbies, etc.
Biological samples	Cord blood	Endocrine disrupting chemicals, hormones, infection/inflammation/immunity/allergy markers, glucose metabolism, chemicals (metals, organic fluorine compounds, etc.), genetic markers
	Blood (mother, father)	Endocrine disrupting chemicals, hormones, infection/inflammation/immunity/allergy markers, glucose metabolism, chemicals (metals, organic fluorine compounds, etc.), genetic markers
	Breast milk	Antioxidants, phytoestrogens, chemicals
	Urine (mother, father, children)	Drugs, chemicals, cotinine, etc.
	Vaginal swabs	Bacterial infection, antibodies, cytokines
	Placenta, cord, meconium	Antibodies, cytokines, chemicals, etc.
	Hair, nail, saliva (mother, father, children	Cotinine, mercury, cortisol
Environmental samples	Indoor air	Particles, volatile organic compounds, aldehydes, nitrogen oxides, ozone, carbon monoxide, etc.
	House dust	Allergens, endotoxins, metals, pesticides
	Drinking water	Disinfection byproducts, volatile organic compounds, metals, pesticides, coliforms, etc.
	Soil	Metals, pesticides
	Noise	
Medical testing	Physical attributes	Height, weight, abdominal circumference, skin fold thickness, etc.
	Blood pressure	
	Ultrasound assessments	
	Clinical assessments (pregnancy, newborn)	
	Mental and physical development	

Items in parentheses are the study subjects

Prepared by the STFC

study location to participate in the study. The study plans to follow children from before birth until age 21. About 50 Study Centers, which will be responsible for one or multiple study locations, will be selected among applicants. As of the end of year 2008, 27 Study Centers had been selected. Additionally, the seven Vanguard Centers have been conducting pilot studies since 2005 and continue to serve as Study Centers. Many Study Centers take the form of a joint study organization led by a university working with their neighboring universities and medical institutions. These Study Centers will implement local studies under the Program Office and the Coordinating Center.

Annual funding levels for the study are shown in Table 1. Approximately 50 million dollars were already spent during the planning phase, and in fiscal 2008, the annual funding reached 110 million dollars.

3-3 National Children's Study Questions and Methods

The study questions can be roughly divided into influences on health and environmental exposures (Table 2). Methods of collecting information are diverse: questionnaires via home visits or phone interviews; collection of cord blood, blood, breast milk, and other biological samples and analysis of these samples for various exposure indicators, effect indicators, and genetic markers; collection of indoor air, drinking water and other environmental samples and analysis of these samples for chemicals and other substances; clinical assessment data at medical institutions; and mental and physical development assessments through various medical exams. The previously mentioned hypotheses are based on the mutual effects of genetic and environmental factors and the study questions reflect these effects. The study will be carried out at different developmental phases such as before pregnancy, during each trimester, when children are newborns, infants, young children, and youths. The study questions are different for each phase and the target population includes not only mothers and children but also fathers.

4 Research Trends in Europe and Other Countries

Figure 4 shows major cohort children's studies on the environment and health from around the world. In addition to the United States, Norway and Denmark are conducting large birth cohort studies as national projects. Norway's study began in 1999. Since then, pregnant women have been enrolled continuously, and approximately 90,000 people had participated as of 2007. In this study, children are followed until age six. Denmark's study began in 1997 and approximately 100,000 people had participated as of 2002. It is not clearly set how long children will be followed. The studies in both Norway and Denmark address pregnancy, birth, child development, asthma, and

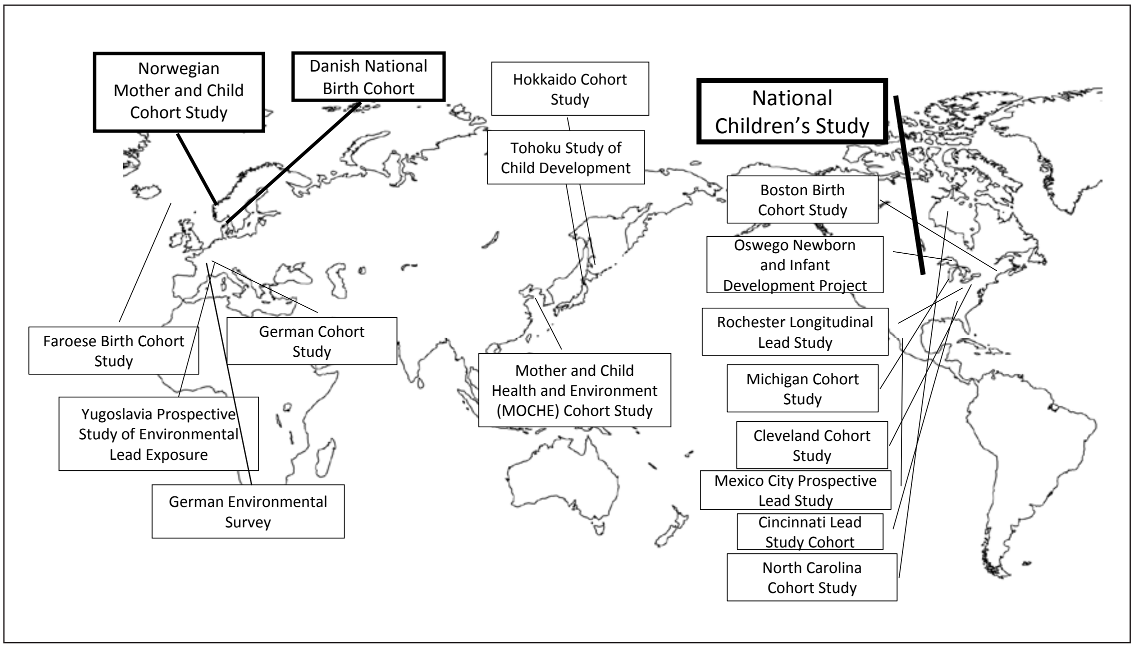


Figure 4 : Major Cohort Children's Studies on the Environment and Health around the World

The reference[3] was partly modified by STFC

other illnesses. In contrast to the National Children's Study, the studies in Norway and Denmark did not formulate hypotheses before implementing the studies, but rather intend to collect as much information as possible. Various registration systems related to birth and medical care exist in both countries, making it easy to conduct these studies.

In Korea, the Ministry of Environment has been leading a follow-up study until age five in three cities, including Seoul, since 2006. The study collects information about biomarkers in blood and urine, physical and mental development, and allergies and asthma. It aims to study how environmental exposure affects the health of mothers and children.

5 Research Trends in Japan

5-1 Existing Research

The Hokkaido Cohort Study led by Hokkaido University is the largest study in Japan.[4] The study, which aimed to enroll approximately 20,000 pregnant women in Hokkaido between 2002 and 2005, plans to follow children until age five or six and is still ongoing. The aim of the study is to find susceptibilities to birth defects and hormonally active environmental agents. The study includes measurements of various hormonally active environmental agents in mothers' blood, cord blood, and breast milk and also genetic analysis.

Additionally, in fiscal year 2004, the Research Institute of Science and Technology for Society launched an R&D Project: Identification of Factors Affecting Cognitive and Behavioral Development of Children in Japan Based on a Cohort Study (FY2004 to 2008) (the Japan Children's Study). By taking the cohort study approach and targeting infants and small children, the study aims to determine the influence of social and living environments on mental, physical, and language development as well as their mechanisms, in particular, the neural base for social skills and the acquisition process during different developmental phases. The interim evaluation conducted in July 2006 recognized its significance as a prospective longitudinal study. However, it determined that it would not be viable as a longitudinal study because it lacks an integrated study plan or a design for important details, and, as such, the study was cancelled in fiscal 2008.[5]

The Ministry of Health, Labour and Welfare is conducting the Longitudinal Survey of Babies in the 21st Century, following approximately 50,000 babies born in Japan in the periods between January 10 and 17, 2001 and between July 10 and 17, 2001.[6] By continuously studying actual conditions and changes over the years of babies born in the first year of the 21st century, the survey aims to obtain basic information for making, planning and implementing ministry policies. Survey questions include guardians, cohabitants, employment,

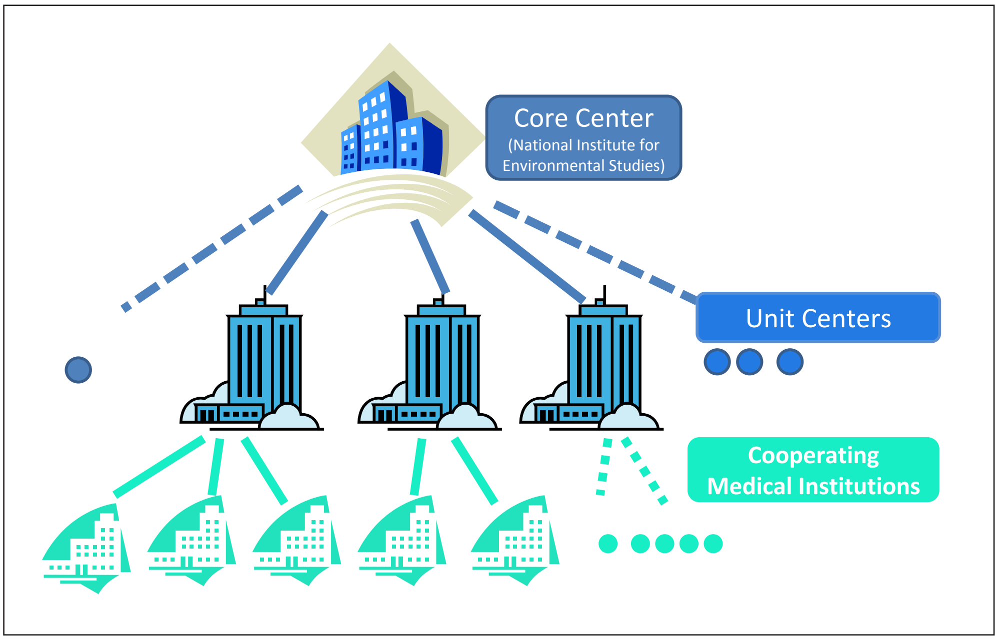


Figure 5 : Implementation System for the National Study on Children's Environment and Health conducted by the Ministry of Environment

The reference[7] was partly modified by STFC

working hours, parental sharing of household chores and child rearing, housing conditions, efforts and attempts at child rearing, advantages of having a child, disadvantages of having a child, worries and anxieties about child rearing, breastfeeding, income, the child's diet, health, lifestyles, plays, etc. The survey uses questionnaires and is conducted every year as an approved statistical survey by the Statistics and Information Department of the Ministry of Health, Labour and Welfare. Some survey questions, such as children's living environments and parental perspectives on childrearing, can also be seen in the hypotheses of the National Children's Study. The targeted dates of birth are limited (approximately 4.6% of the total births in 2001); however, all Japanese are the subjects, and the collection rate for the first survey was high at 87.7%. In the following fiscal years, the collection rate surpassed 90%, and approximately 39,000 people answered the sixth survey in 2007. The very high follow-up rate is probably due, in large part, to the fact that it is conducted as a national statistical survey. However, the surveys are conducted via mail and are limited to self-completed questionnaires.

5-2 New Trends in Environmental Health at the Ministry of Environment

The Ministry of Environment has been holding international symposiums and conducting research on children's environmental health since 2003. In 2006, in response to proposals by the Ad Hoc Committee on Children's Environmental Health, the ministry launched a priority project study on children's environmental health and began exploring the necessity for a large epidemiological study. Based on the result, a pilot study for the National Study on Children's Environment and Health was launched in fiscal 2008. A full-fledged study will begin in 2010, aiming to follow approximately 60,000 children throughout Japan until age 12. First, some ten Unit Centers will be selected throughout Japan. They will be comprised of social medicine, obstetrics and gynecology, and pediatric departments at universities and research institutes. With cooperation from regional medical organizations, these Unit Centers will be responsible for enrolling pregnant women, collecting biological samples, and other operations that require contact with the target population. In addition, a Core Center will be established at the National Institute for Environmental Studies. The center will be responsible for planning and coordinating the overall study, maintaining biological samples, and managing data and information (Figure 5). The study addresses issues similar to those of the National Children's Study, including the relationship between exposure to various chemicals and physical and mental development, birth defects, allergies, and metabolism and endocrine-related disorders, as well as related factors. The study will be finalized through the examination process, which includes publicly inviting people to propose hypotheses. The study aims

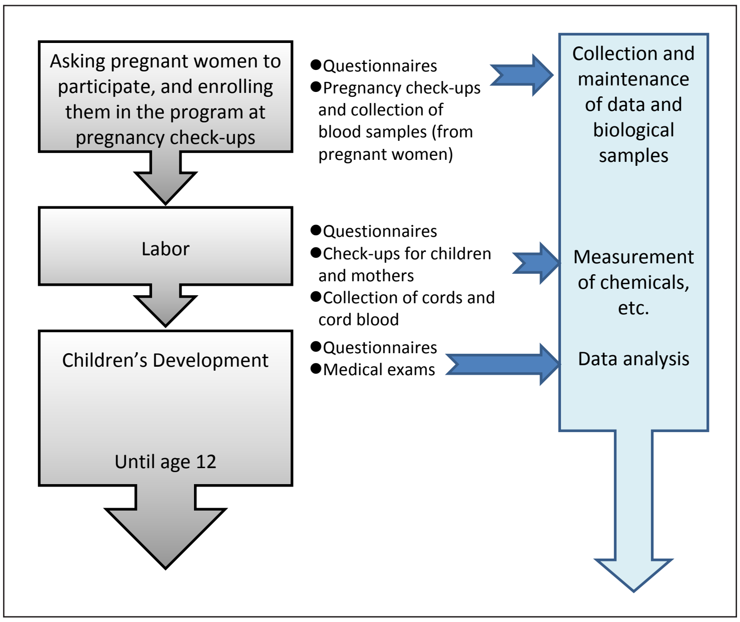


Figure 6 : Summary of the National Study on Children's Environment and Health conducted by the Ministry of Environment

The reference[7] was partly modified by STFC

to follow children until age 12; however, whether the study should be extended and how long biological samples should be maintained will be reevaluated before the study ends.

6 Future Issues and Prospects

In recent years, in other disciplines as well, countries worldwide have been conducting large national studies targeting people. It is thought that each country intends to collect information about the people in these studies as part of its national strategy and accumulate it as intellectual property for the health and medical care of future generations. The United Kingdom, for example, is conducting research to determine the effects of lifestyle, the environment, and genetics, targeting 500,000 adults.[8] Japan launched the BioBank Japan Project and provided approximately 20 billion yen to analyze genes over a period of five years between 2003 and 2007 and collected blood samples from about 200,000 people. Similar research is being planned and conducted in the United States as part of its national strategy for science and technology. The National Children's Studies can be characterized in the same way.

As can be seen in the United Kingdom's epidemiological study elucidating the relationship between smoking and lung cancer or Japan's multi-purpose cohort study (JPHC Study) by the Ministry of Health, Labour and Welfare that found cancer-related factors, many large epidemiological studies targeting adults have been conducted around the world. However, few large epidemiological studies have targeted unborn babies and children. Countries worldwide have been promoting research on child health and the environment since the vulnerability of children began drawing attention in the international community, as can be seen in the 1997 Declaration of the Environment Leaders of the Eight on Children's Environmental Health. Furthermore, it is thought that each country intends to accumulate intellectual property concerning the people's health and medical care as part of its national strategy.

There has been increasing concern about children's living environments both administratively and academically as exemplified in the Longitudinal Survey of Babies in the 21st Century conducted by the Ministry of Health, Labour and Welfare, the pioneering Hokkaido Cohort Study subsidized by the Ministry of Health, Labour and Welfare, the Japan Children's Study conducted by the Research Institute of Science and Technology for Society, and the National Study on Children's Environment and Health planned by the Ministry of Environment. These studies were planned with specific goals, and these goals and their study subjects are similar to the hypotheses of the National Children's Study. However, the United States combines different hypotheses in one national research project, and as such, there is a difference in national strategy between Japan and the United States. If we consider the difficulty of carrying out a cohort study and correlating diverse factors concerning child health and development, it is necessary from the perspectives of scientific rationality and research efficiency to find ways to verify objectives and hypotheses in each field on a common basis.

For research on child health and the environment, the longitudinal cohort study approach is common worldwide. This is because, as previously mentioned, cohort studies are recognized as necessary to evaluate long-term health and the many factors affecting it throughout the different developmental phases extending from before birth to adulthood. However, in Japan, due to a lack of appropriate institutions to carry out a long-term study, the Japan Children's Study did not turn into a longitudinal study, although evaluators recognized the importance of the study as a prospective longitudinal study. This exemplifies the difficulty of implementing a long-term cohort study targeting many people's lives in Japan. Other difficulties include securing long-term funding and a lack of specialists and public support systems.

Furthermore, the National Children's Study takes multiple approaches to obtaining continuous long-term cooperation from the target population. Communicating with the target population is, of course, emphasized. The study attempts to establish cooperative relationships with local organizations, institutions, and affiliated groups at various levels and allocates specialists to the core divisions at the regional study centers in order to maintain those relationships. The National Children's Study calls this division's work "community outreach." Japanese epidemiological researchers also recognized the importance of community outreach, which is equivalent to nemawashi (consensus-building), as can be seen in the Japan Children's Study. However, while they thought that it should be considered when they implemented the study, they later failed to incorporate it into the organization or study elements.

As the growing concern for privacy protection suggests, the relationship between the bodies responsible for implementing research and the target population has been greatly changing. In any large national research that attempts to accumulate intellectual property concerning the people's health and medical care, it is necessary to systematically communicate to the target population in a precise yet easy-to-understand manner how research results will benefit the individual and public health and welfare as well as the environment.

References

[1] NIH News, National Children's Study Begins Recruiting Volunteers, January 13, 2009 : http://www.nichd.nih.gov/news/releases/jan12-09-NCS-Recruiting.cfm

[2] The National Children's Study Research Plan, September 17, 2007 : http://www.nationalchildrensstudy.gov/research/studydesign/researchplan/Pages/ResearchPlan.pdf

[3] Environmental Health Department, Ministry of Environment, March 2008, Report from the Committee on the Epidemiological Study for Children's Environmental Health : http://www.env.go.jp/chemi/report/h20-02.pdf

[4] Hisanori Minakami, Welfare, Labour and Science Research Subsidies Report, "Congenital Defect Monitoring through a Positive Cohort Study Focusing on Understanding Risk Factors of Hypospadias and Cryptorchidism and Receptivity to Endocrine Disruptors," 2007

[5] Evaluation Committee, Research Institute of Science and Technology for Society, Japan Science and Technology Agency, Evaluation Report: Interim Evaluation for R&D Program Projects, R&D Program "Brain-Science and Education (Type II)," R&D Focus Area "Brain-Science and Society;" Annual Evaluation for the R&D Project: "Identification of Factors Affecting Cognitive and Behavioral Development of Children in Japan Based on a Cohort Study (Japan Children's Study)," 2007 : http://www.ristex.jp/examin/brain/plan/pdf/ind04.pdf

[6] Statistics and Information Department, Minister's Secretariat, Ministry of Health, Labour and Welfare, the Sixth Longitudinal Survey of Babies in the 21st Century (Fiscal 2006), 2008 : http://www.mhlw.go.jp/toukei/list/27-6.html

[7] National Study on Children's Environment and Health Homepage, Ministry of Environment : http://www.env.go.jp/chemi/ceh/index.html

[8] UK biobank: http://www.ukbiobank.ac.uk/

Profile

Hiroshi NITTA
Affiliated Fellow,NISTEP
Manager, Environmental Epidemiology Section, Environmental Health Division, National Institute for Environmental Studies
http://www.nies.go.jp/

His major research focus is environmental epidemiology. He has been studying the effects of air pollutants on health, has conducted research on elementary school students and other residents, and has worked to assess exposure to indoor and outdoor air pollutants. He is also a provisional member of the Central Environmental Council.

(Original Japanese version: published in March 2009)

4

Trends in Research and Development of Nanoporous Ceramic Separation Membranes
- Saving Energy by Applying the Technology to the Chemical Synthesis Process -

Yuji IWAMOTO
Affiliated Fellow
Hiroshi KAWAMOTO
Nanotechnology and Materials Research Unit

1 Introduction

Energy consumption in the chemical industry accounts for about 15% of the consumption in the entire industrial field,[1] and about 40% of such energy consumption accounted for by separation and refinement through distillation operations.[2] The existing process of separating various types of mixtures is an energy-intensive process, and achieving both a significant reduction of energy necessary for separation and an improvement of the efficiency of processes is one of the chemical industry's priority issues when it comes to reducing the emissions of global greenhouse gas. The refinement process that uses separation membrane is one of the technologies that show promise in achieving significant energy savings compared to the conventional distillation method. So far, organic polymer separation membranes have mainly been used.

For the porous separation membranes that are suited to the chemical synthesis process, it is necessary to control the pore diameter at the nanoscale according to the size of the product material that is to be separated, as well to selectively separate only the product material. Components for the porous separation membrane that have the potential to fulfill such functions include organic polymer systems, such as aromatic polyimide and fluorinated polymer, as well as ceramics, such as silica systems and zeolite systems. However, organic polymer separation membranes that are currently used have limited heat resistance, chemical resistance, pressure resistance and mechanical strength. On the other hand, zeolite-based ceramics are attracting attention as next-generation membrane material with the potential to breakthrough such limitations held by components for organic polymer separation membrane (membrane materials/support substrates).[3,4]

This paper focuses on zeolite ceramics, and describes the microscopic structure and physicochemical characteristics of membrane materials necessary for developing a nanoporous separation membrane; the manufacturing process of separation membrane components; trends in research and development related to separation membrane components, cells, modules and systems; and the energy saving effects of various chemical synthesis processes expected through the separation membrane system. In addition, it also proposes issues to be researched and developed, and makes suggestions on how to proceed with research and development in the future.

2 Application of Nanoporous Ceramic Membranes to Chemical Synthesis Process

2-1 Previous application of nanoporous separation membranes

Separation membrane refers to a membrane used to cause target fluids and gases to permeate and be separated or refined. Research and development of separation membrane technology for various sizes of substances, from the microscale to the nanoscale, had been implemented in the past. Filtration membranes used to separate substances at the micrometer level include diesel particulate filters (DPFs), while filtration membranes for substances the size of few hundred nanometers or more are used for recycling and sterilization of industrial wastewater. Ultrafiltration membranes used to separate substances the size of a few nanometers are applied to water purification, separation or concentration of molecules such as enzymes, and artificial dialysis or removing viruses in the field of medicine. Furthermore, nanoporous separation membranes used to separate very small substances less than a few nanometers in size are currently being developed for practical application in removing polymer molecules (proteins) and concentrating fruit juice or dairy products. Among such research and development, that focusing on nanoporous ceramic membrane, on which ordered, ultrafine pores are consecutively lined up, is attracting the strongest attention.

Figure 1 shows a conceptual diagram of a nanoporous ceramic membrane, cell and module, and the types of separation/filtration membranes and substances to be separated. The module in this figure is a separation membrane module that places many circular membrane cells made of catalytically inactive materials, such as silica and palladium. The principle of separation and filtration using membrane is also shown.

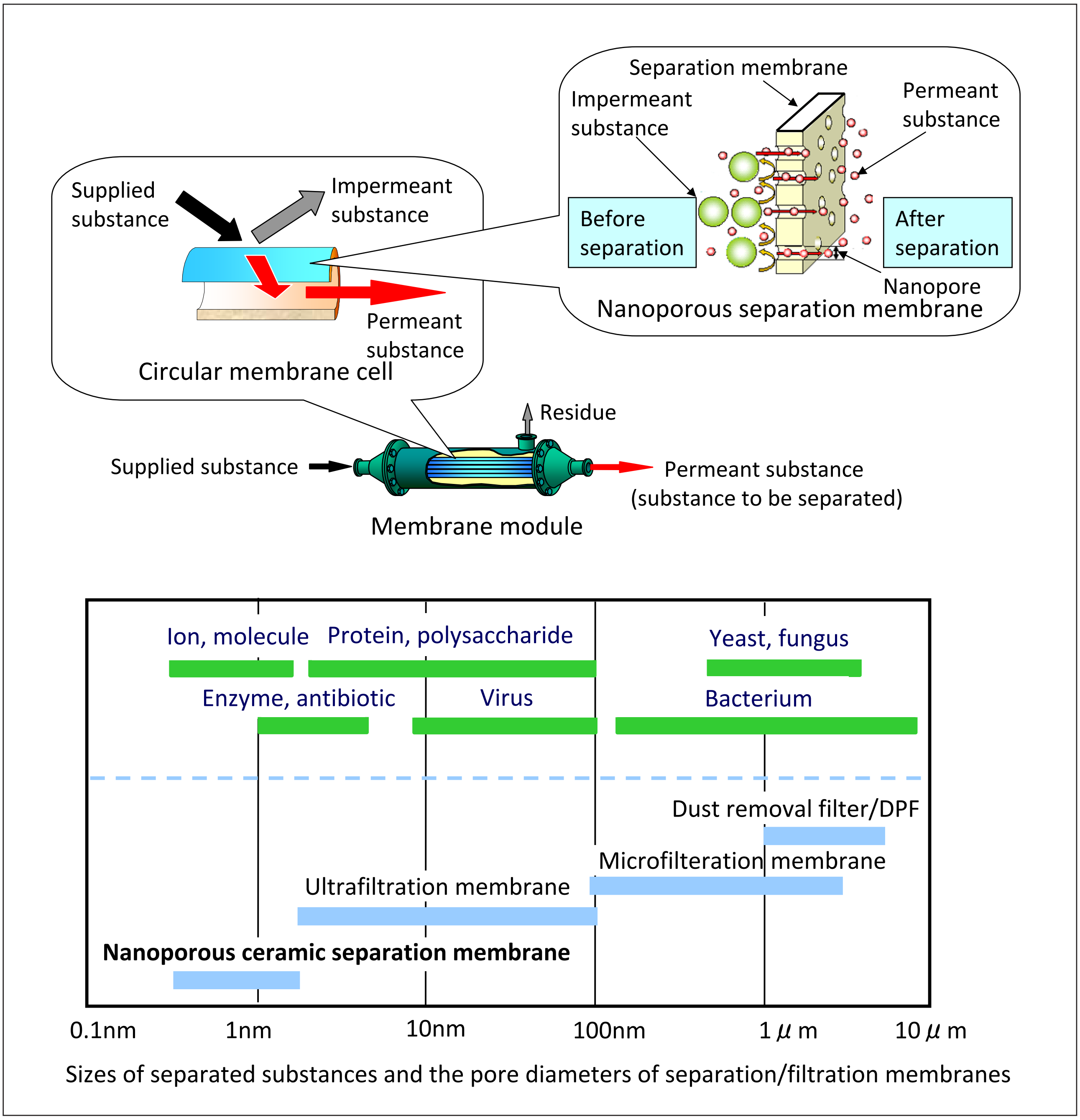


Figure 1 : Conceptual diagram of nanoporous ceramic membrane, cell and module, and the types of separation/filtration membranes and substances to be separated

Prepared by the STFC

Table 1 : Comparison of the characteristics of separation membranes by different materials

Membrane material	Heat resistance	Chemical stability	Major separation substances	Cost	Characteristics
Nanoporous ceramic	○	○	Hydrocarbon Hydrogen Oxygen Carbon dioxide Water (dehydration)	△	•High heat resistance •High chemical resistance •High mechanical strength •Large amount of resources
Organic polymer	×	△	Hydrogen Oxygen Carbon dioxide Water (dehydration)	○	•Easy fabrication •Low heat resistance •Low chemical resistance •Low mechanical strength •Degraded by hydrocarbon separation
Metal	△	△	Hydrogen	×	•Unusable under low temperature (< 300℃) •Small amount of resources •Low resistance to poisoning

Prepared by the STFC and based on Reference[1]

2-2 Advantages of nanoporous ceramic separation membranes

Table 1 shows the comparison of the characteristics of various separation membranes with different materials. Organic polymer separation membranes that have been developed for chemical synthesis processes have advantages in their low cost, but they still have limited heat resistance, chemical resistance and mechanical strength. Metallic separation membranes, represented by dense palladium membrane, are known for their superior performance in hydrogen separation. However, the fact that they can only work in a restricted temperature range, property degradation caused by hydrogen embrittlement and sulfur poisoning, and the high cost of the rare metal used, are the significant problems hindering their practical application in chemical synthesis processes.

In contrast, nanoporous ceramic membranes using zeolite show superior heat resistance and chemical stability under the conditions of various chemical synthesis processes, including extremely high temperatures of more than 500° C, so they are most promising as a hydrocarbon separation membrane. In addition, by choosing materials with superior mechanical properties for the substrate that supports the membrane, zeolite is a potential component expected to realize an innovative separation process.

2-3 Energy-saving effect of introducing a nanoporous ceramic separation membrane system in the chemical industry

A zeolite separation membrane with a regular nanoporous structure is expected to be applied in the future in fields such as the dehydration, separation and refinement of organic compounds, by replacing some of the current separation/refinement processes using the distillation method, or replacing the entire process with the processes using separation membranes. It is expected that this will significantly reduce the energy consumption in the chemical industry.

For example, Figure 2 shows the estimation of the energy-saving effect that is expected in a plant that separates/refines the mixture of water and acetic acid, when conventional distilling columns are replaced with a system composed of nanoporous separation membrane modules. Assuming the thermal energy necessary for separation through the distillation process is 162,000kcal/h, the energy necessary for separation/refinement through pervaporation in the water-selective nanoporous separation membrane process is estimated to be 27,000kcal/h. Therefore, an energy saving of about 85% in terms of necessary calories can be realized. Furthermore, if an acetic-acid-selective separation membrane could be introduced, it is estimated that the necessary energy would be as low as 5,200kcal/h, which is a reduction in energy by more than 90%.[2]

The performance of a separation membrane can be compared with the α value (refer to Note 2).The

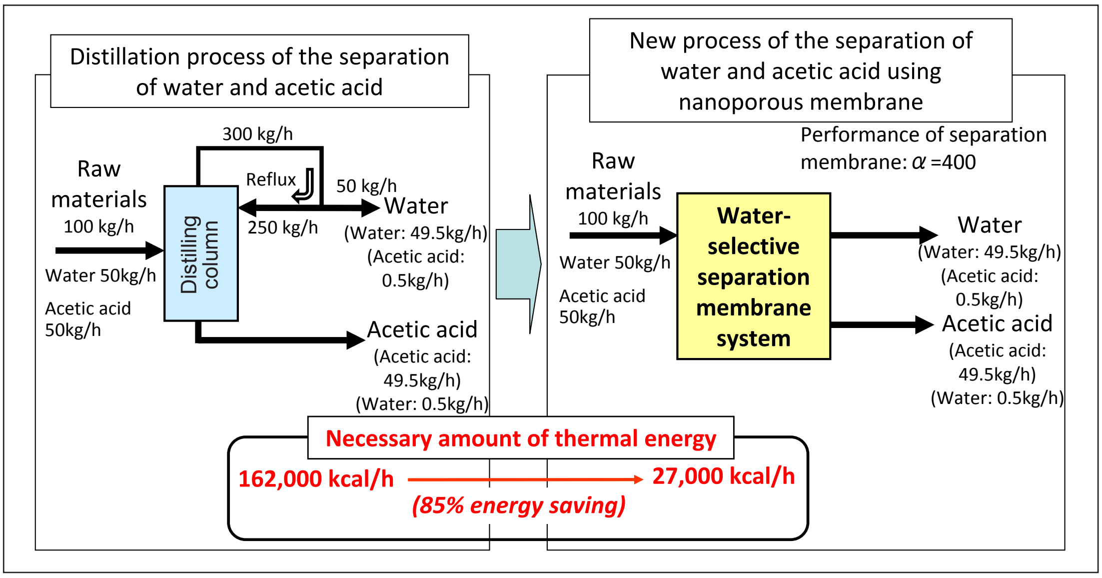


Figure 2 : Estimation of energy-saving effect expected in a plant that separates/refines water and acetic acid when a nanoporous separation membrane system is introduced

Prepared by the STFC and based on Reference[2]

current performance of acetic-acid-selective zeolite membrane is about α=20; the performance is not high. If a nanoporous ceramic membrane with a high performance level of about α=400, is developed in the future, and water-selective or acetic-acid-selective separation membrane systems are introduced, energy- and space-saving separation/refinement processes, without distilling columns, will be realized. However, in order to completely remove the distilling column used in a conventional process and replace them with a system using regular nanoporous ceramic separation membrane, it will require major structural changes for the chemical plant, so such a full replacement is rather unrealistic. Thus, it is expected that the energy-saving in chemical synthesis processes will begin with the partial introduction of the nanoporous ceramic separation membrane system in the conventional distillation process.

Besides this application, there are even higher expectations regarding the use of separation membrane in the case of a distillation operation of organic mixtures with small differences in boiling points. For instance, the distillation in naphtha crackers, which is implemented in the largest plants in the petrochemical industry, separates refined substances using different boiling points by compressing and cooling gaseous components. It is also one of the most energy-intensive processes. In the case of separating ethylene and ethane, there will be around 120~150 theoretical distillation column plates. In the case of separating propylene and propane, the number of theoretical plates will be as large as around 250. The chemical industry has been demanding simplification of such refinement processes for a long

[NOTE1]
The amount of thermal energy necessary to separate water and acetic acid by distillation was calculated as follows: Based on the equilibrium relation of liquid and gas in a binary system under ordinary pressure, reflux volumes of ingredients that are insufficiently separated by distillation in many distillation columns comprised of concentration and recovery stages are evaluated, and the thermal energy necessary for cooling the condenser, corresponding to the reflux volumes, is assumed as the amount of necessary energy.

[NOTE2]
The performance of separation membrane represented by α is defined as α=[Y/(1-Y)]/[X/(1-X)], when the concentration of the supplied substance is X and the concentration of the permeant substance is Y.

[NOTE3]
Pervaporation is a method used to separate permeant substances by supplying liquid to the separation membrane and evaporating the liquid while aspirating the membrane at the opposite side of the supply side with devices such as vacuum pumps.

time. If the separation membrane process can be applied to various kinds of isomeric separation (e.g., xylene, diisopropylbenzene, cresol, butene, phenol), the downsizing of manufacturing equipment and an increase in efficiency and cost reduction, in addition to energy-saving, can be achieved. In the case of the petroleum refinement industry, similar effects can be expected if a new separation membrane process can be applied to the separation of aromatic hydrocarbon from petroleum fraction (separation of aroma, naphthene and paraffin). In addition, the need for the dehydration operation of ethanol, which is currently under development as a biofuel for practical use, is expected to increase greatly in the future, and it is forecasted that the global market for a dehydration separation membrane system will expand. Demands for separation membrane technology from industries such as the petroleum refinement and petrochemistry industries are becoming more and more diversified. At the same time, demand for energy-saving is also increasing. In this context, distillation operations using many distillation columns comprised of concentration and recovery stages are estimated to take up more than 70% of the total energy consumption in the entire operation of separation and refinement, and energy-saving holds more importance than ever.[5]

3 Nanoporous Zeolite Separation Membrane

Zeolites are hydrous crystalline aluminosilicates with tetrahedral structural units consisting of $(SiO_4)^{4-}$ and $(AlO_4)^{5-}$ (collectively referred to as TO_4). Their composition formula is expressed as $Na_xSi_yAl_xO_{2(x+y)}$ ($x \leqq y$). There are currently more than 150 different types of zeolites known.[6] A unit of TO_4 forms a crystal by sharing the oxygen that makes up its four peaks to connect three-dimensionally to four adjoining TO_4 units. This crystal is porous, and its pores have an opening diameter of about 0.4–0.8 nm, so it has a molecular sieving function, wherein molecules smaller than the size of the opening can enter the pores but larger molecules cannot.

As shown in Figure 3, nanoporous zeolite has nanopores that are slightly larger than the diameter of permeant molecules. It is drawing attention as a material for molecular sieving separation membrane, and as a material with excellent characteristics that cannot be achieved with an organic polymer membrane, such as heat resistance, chemical resistance and high durability. Nanoporous zeolite is expected to be used for a wide variety of purposes, such as pervaporation separation, gas separation and catalytic membrane reactors.[7,8] In general, nanopores of zeolite are briefly categorized according to the number of oxygen atoms (number of members) included in the ring structure of the opening. However, the number of members and the diameter of the nanopores are unfixed. This is due to the differences in the shapes or alignments of surfaces that form the ring structures. One of the known methods that are effective for controlling nanopore diameter of zeolite is ion exchange. A typical example shows that when the cation on the eight-membered ring surface of an A-type zeolite is sodium ion (Na^+), the effective diameter of nanopores will be about 0.4 nm, but when it is potassium ion (K^+), the diameter of nanopores will be about 0.3 nm. When the cation is calcium ion (Ca^{2+}),

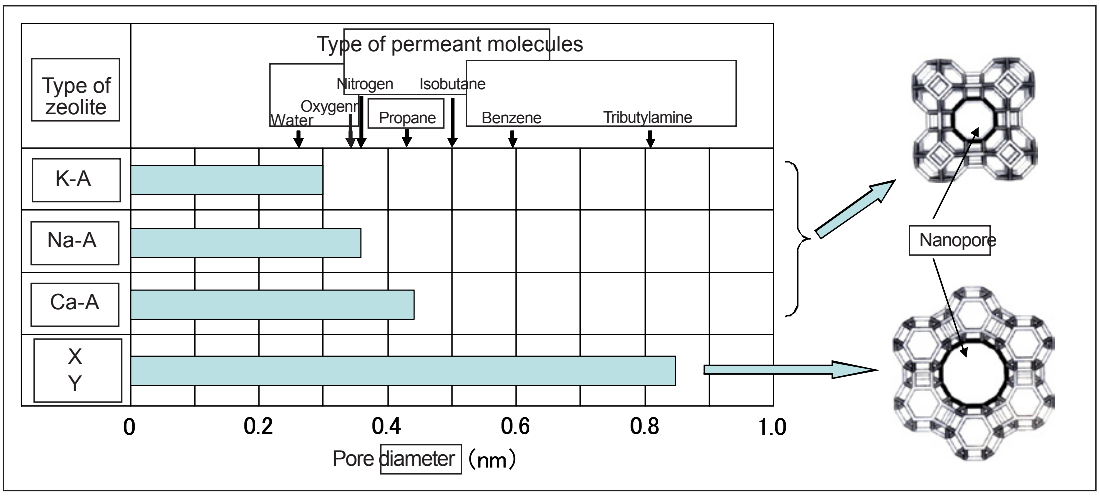


Figure 3 : Diameters of the nanopores and structures of typical zeolites (A-, X- and Y-Types)

Prepared by the STFC and based on Reference[6] half of the ions on the eight-membered ring are empty, and in that case the effective diameter of nanopores will be about 0.5 nm.[6]

A substance wherein all $(SiO_4)^{4-}$ units share oxygen atoms at their peaks and are connected three-dimensionally is called a tectosilicate, while a substance that does not contain aluminum in its framework composition is silica (SiO_2). On the other hand, when the substance partially contains aluminum, the positive charges that become deficient due to Si4+ being replaced with Al3+ are supplemented with other cations (e.g. Na^+, H^+ and Ca^{2+}), and the composition is $M_nAl_nSi_1\text{-}_nO_2$ (when M is a monovalent cation). The extent to which the Si^{4+} in the framework of zeolite is replaced with Al^{3+} and other cations will have a large effect on the chemical property of the zeolite (such as its hydrophilic property, resistance to chemicals and acidity). Because of this characteristic, even if all the various kinds of molecules included in a mixture are smaller than the diameter of the nanopores of the zeolite, it is possible to let only certain desired molecules be absorbed by zeolite by using the differences of the affinity of the molecules to the zeolite. For example, in the case of a zeolite that contains less silica and has high hydrophilicity, the ranking of the amounts of atmospheric component gases absorbed under a fixed partial pressure will be as follows:

$H_2O>CO_2>N_2>O_2>Ar$

In the case of hydrocarbons, alkenes with a carbon-carbon double bond, represented by ethylene gas ($H_2C{=}CH_2$), and aromatic series, such as toluene, have higher affinity with zeolite compared to alkanes (saturated hydrocarbon). Therefore, when applying zeolite as a nanoporous separation membrane, its separation performance can be dramatically improved by not only controlling the diameter of the nanopores according to the molecule size of the substance to be separated, but also by using the selective absorption function based on the chemical affinity of the target molecule.

4 Current Status of Manufacturing Zeolite Separation Membrane

4-1 Hydrothermal synthesis method

Zeolites exist in nature, and natural materials extracted from minerals containing zeolites, through thermal or chemical treatments, are in use. For the artificial synthesis of zeolites, the hydrothermal synthesis method is used in general. This method synthesizes and grows crystals by using the phenomenon that substances are more easily dissolved in water at high-temperature and high-pressure. Silica does not dissolve in ordinary water, but by using the phenomenon that it dissolves in hot liquid, it can be used for zeolite synthesis in an autoclave, under the condition of high-temperature and high-pressure water. Alumina sources that serve as ingredients in zeolite are aluminum metal, sodium aluminate and aluminum hydroxide. Silica sources include silica powder, silica gel, colloidal silica, tetramethylsilane, silicon alkoxide, and sodium silicate, such as liquid glass. As for synthetic conditions other than the relative proportions of components, there are important factors, such as temperature, pressure, reaction time, crystallization modifier and whether there is a seed crystal or not.

On the other hand, because there are problems with zeolite self-supported membranes, such as low mechanical strength and low density, it is usually manufactured as a polycrystalline membrane wherein zeolite crystals are precipitated in high density onto porous substrates. Most of the MFI-type zeolite membranes are formed onto porous support substrates in an autoclave, using wet silica, colloidal silica and tetraethoxysilane for silica sources as ingredients and tetrapropylammonium bromide as an organic structure-directing agent (template).

4-2 Method with zeolite seed crystal

Regarding dehydration membrane for pervaporation, A-type zeolite is already in practical use, and is manufactured with the membrane formation process as shown in Figure 4. Porous ceramic support substrates (Figure 5 (a)) are coated with seed crystals (Figure 5 (b)) and then immersed in aluminosilicate gel for hydrothermal synthesis under atmospheric pressure, at 100°C for 3~4 hours. This will form a polycrystalline membrane with a thickness of about 10–20 μm, consisting of primary crystal particles about a few micrometers in size (Figure 5 (c)). Such a structure is formed because gelatinous substances exist on the surface of porous substrates during the initial stage of synthesis, and nucleation and crystal growth proceeds gradually in the gel.[5,9]

This method of coating zeolite seed crystals

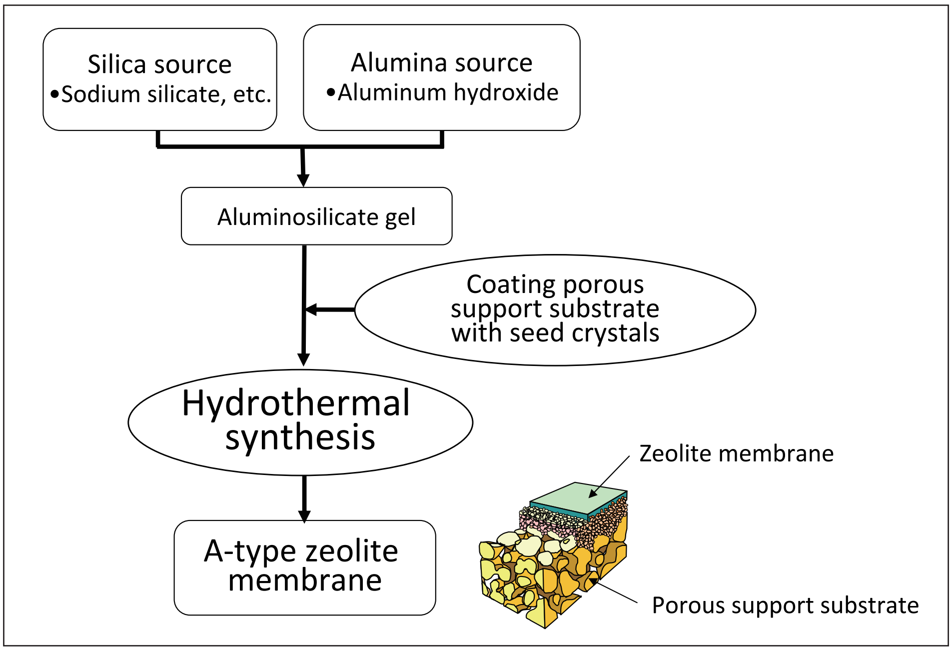


Figure 4 : Process of the formation of zeolite polycrystalline membrane

Prepared by the STFC

onto a support base and letting them grow through hydrothermal synthesis to make a zeolite membrane is effective for manufacturing high separation-performance, high density zeolite membrane. To coat seed crystals, several other methods are being attempted, including immersing the support base in a suspension or coating slurry solution, as well as electrophoresis and laser ablation methods for attaching zeolite pieces to a supporting base. It is known that by using microwave heating for hydrothermal synthesis, crystallization is accelerated and a dense, thin membrane can be obtained.

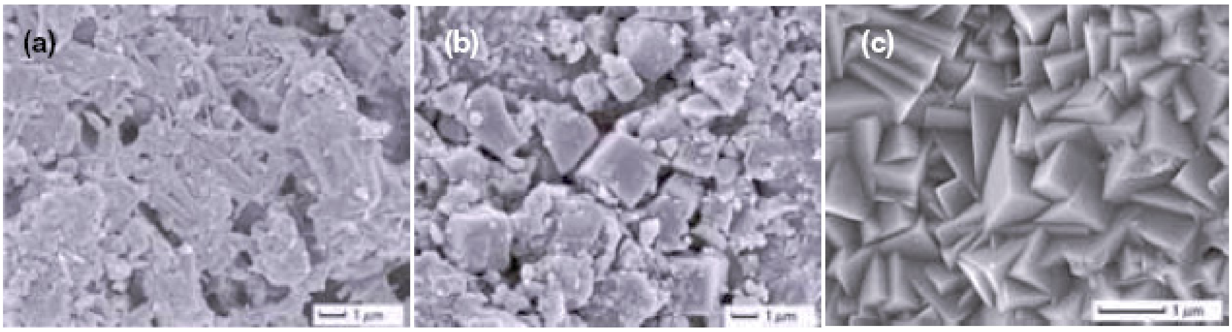
4-3 Dry gel conversion (DGC) method

It was confirmed that water is not an essential solvent for manufacturing zeolite10], then various methods for crystallizing zeolite without the use of water as a solvent were considered, and it was discovered that MFI zeolite can be obtained with a dry gel that includes silica, or alumina and alkali, under ethylenediamine- triethylamine-water vapor11]. In the DGC method, aqueous gel is modified as it is in hydrothermal synthesis. The porous support substrate is immersed into this gel and the surface is coated. Crystallization takes place after the dehydration. First, zeolite crystals are formed sparsely on the surface of the membrane. The number of crystals gradually increases. At this stage, crystals are formed and grow not only on the surface but also inside the alumina support substrate at the bottom part of the crystal. Zeolite formed inside the porous support substrate starts growing from the bottom of the zeolite crystal that is observed on the surface of the support substrate, and then spreads throughout the support substrate and increases in density.[12] In the DGC method, crystallization reaches almost 100%, and a zeolite membrane that is more homogeneous compared to that formed by a conventional hydrothermal synthesis will be produced. It also generates less waste liquid.

4-4 Problems with Synthesis Methods for Separation Membrane

Zeolite membrane has unique nanopores due to the crystal structure, so it can sieve molecules by having them permeate through the nanopores, if the structure is defect-free. However, because zeolite membranes are polycrystals, in many cases there are small defects at the interface between crystals (grain boundary)

[NOTE4]
The International Zeolite Association (IZA) categorizes various kinds of zeolite structures with three-letter structure codes. The MFI-type is a kind of zeolite that has ten oxygen atoms in the ring structure (ten-membered ring) and a framework structure with a nanopore diameter of about 0.4~0.6 nm.



(a) Porous support substrate (b) Seed crystal (c) A-type zeolite formed by hydrothermal synthesis

Figure 5 : Microscopic structure of A-type zeolite polycrystalline membrane

Prepared by the STFC and based on Reference[5]

through which molecules can bypass (pinholes). These pinholes lower the separation performance of the membrane. Therefore, even though many articles are published on the gas separation of newly developed zeolite membrane, there are only a very few separation membranes that can be used in practice at present. A-type zeolite membrane, for example, is susceptible to moisture content, and it is extremely difficult to make a membrane free of pinholes under present circumstances.

Proposed possible formation mechanisms of zeolite membrane by hydrothermal synthesis are as follows:

1) Nucleation and crystal growth in a solution, followed by precipitation on a support substrate;
2) Nucleation in a solution followed by settling onto a support substrate and crystal growth
3) Settling of amorphous gel onto a support substrate as well as nucleation and crystal growth; and
4) Nucleation on a support substrate followed by crystal growth.

However, in order to synthesize regularly ordered nanoporous zeolite separation membrane with an easily reproducible method, it is necessary to conduct further analysis, evaluation and verification related to these formation mechanisms.

5 Current Status of the Analysis and Evaluation of the Microscopic Structure of Nanoporous Zeolite Separation Membrane

Technologies used to analyze and evaluate nanoporous structure, which serve the role of separation, are essential for the research and development of materials for a zeolite separation membrane that is reliable under various usage environments. The functions of separation membrane using zeolite as a dense polycrystalline substance are intimately linked to nanoscale microscopic structural factors, such as the structure of grain boundary, as well as to nanopore diameter and chemical composition.

Figure 6 shows a high-resolution electron microscope (TEM) image of the microscopic structure of zeolite membrane and the simulation image thereof. The structure model of zeolite used for calculation is included in the TEM image. The reason for this is because, although the atomic arrangement of zeolite separation membrane is complicated and it is hard to obtain information on the atomic arrangement directly from the phase-contrast image, it is possible to interpret the TEM image in detail by comparing the phase-contrast image obtained from a sufficiently thin sample with the computer simulation image. Figure 6 shows the strong consistency of the TEM image (a) with its simulation image (b).[13]

It is extremely useful for the research and development of separation membrane to identify an improvement guideline regarding the separation function through analysis and evaluation of the crystal structure of zeolite, and the microscopic structure, including defects in polycrystalline substance. Also, because nanoporous zeolite separation membrane is a polycrystalline membrane, the anisotropic aspect of the crystal growth speed of zeolite, the structure of the grain boundary (Figure 7 (a)), and the structure of the boundary between zeolite and the porous support substrate (Figure 7 (b)) are all important factors concerning its microscopic structure. Although information on such factors offers knowledge on the separation performance and the mechanical properties of the membrane, it can be said that the method using TEM is most useful for the analysis and evaluation of the microscopic structure of nanoporous separation membrane.

However, there are some issues regarding the analysis/evaluation method of zeolite separation membrane using TEM (TEM method), as explained below.

(1) Establishment of thin sample processing method suitable for nanoporous zeolite

For microscopic structure analysis using the TEM method, it is necessary to process a sample for observation into a thickness no more than tens of nanometers, so that electron beams can be transmitted though it. However, in the case of zeolite with a nanoporous structure, it is difficult to make samples thin enough with conventional sample processing methods used for metals and ceramics. Therefore, it is necessary to establish a sample processing method suitable for nanoporous zeolite.

(2) Research and development of TEM observation technology to prevent electron-beam damage

Because zeolite is a material that is easily damaged by the irradiation of a high-energy electron beam, samples cannot be observed under normal TEM observation conditions. Therefore, the low-energy electron beam observation method is employed, where the samples are observed by keeping the irradiation of the electron beam at a low level in order to delay the damage. However, even when this method is used, the same visual field can only be observed for a limited time before damage occurs. Thus, it is essential to research and develop a TEM observation technology suitable for zeolite membrane that takes electron-beam damage into account.

(3) Quantitative evaluation technology for three-dimensional (3D) structure

It is necessary to obtain the 3D structure of the observed sample by applying the computer tomography method using TEM. Once the 3D structure image is obtained, it will be possible to describe the nanopore structure. As a result, it will be possible to quantify information on the microscopic structure of nanoporous zeolite, of which only a mere qualitative interpretation has been possible.

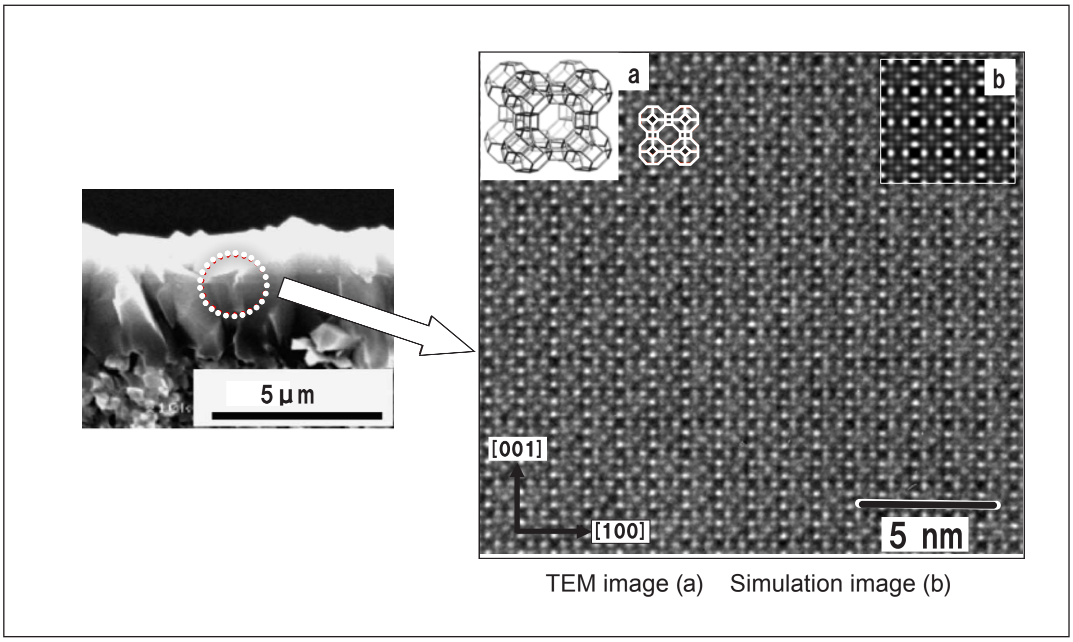
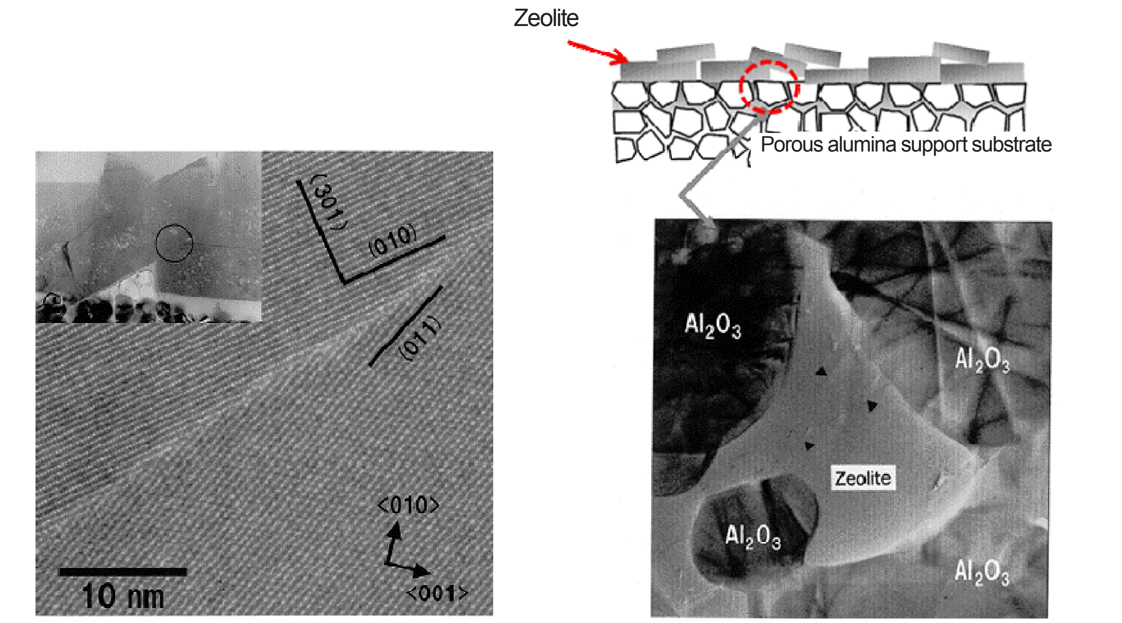


Figure 6 : Microscopic structure of zeolite membrane

Prepared by the STFC and based on Reference[13]



(a) Structure of zeolite crystal grain boundary

(b) Structure of boundary between zeolite and porous support substrate

Figure 7 : Example of TEM structure analysis of zeolite polycrystalline membrane

Photos by Japan Fine Ceramics Center

6 Research and Development on the Application of Zeolite Separation Membrane Components in Various Fields

A-type zeolite membrane, with a molecular sieving function coupled with hydrophilic properties, has the important function of selectively permeating and separating water from a mixture of water and organic substances, such as ethanol and isopropanol. In the case of ethanol and isopropanol, dehydration of a mixture to a moisture content down to about 1,000ppm is possible. The current status of specific research and development on the application of zeolite separation membrane is explained below.

6-1 Dehydration of ethanol

Energy-saving in the concentration and dehydration process is essential in order to realize the industrial production of bioethanol fuels. In 1995, the dehydration property of an ethanol aqueous solution using Na-A type zeolite separation membrane was reported for the first time,[9] and many reports on the pervaporation performance of Na-A type membrane followed thereafter. Figure 8 shows the nanoporous zeolite separation membrane module used for dehydrating bioethanol fuel that was introduced in a pilot plant in Miyako-jima, Okinawa. The separation membrane module is composed of circular separation membrane components made up of 125 tubes, 12mm in diameter and 1m in length, and it achieved an ethanol permeation amount of 530l/h. By combining distillation and membrane separation in the refinement process of bioethanol, a significant energy saving of about 20% was demonstrated in the concentration and dehydration process used to obtain dehydrated ethanol from a fermentation solution.

6-2 Dehydration of isopropanol

There is demand for the effluent produced during lens and semiconductor cleaning in the manufacturing process of precision equipment to be purified by removing isopropanol, and for such isopropanol to be reused. Isopropanol-selective separation membrane through hydrophobic separation will be necessary for such an operation. However, most research on separation membrane has targeted water permeation membrane. In 1997, a high separation membrane performance of α=10,000 or more was obtained with water/isopropanol pervaporation using Na-A type zeolite separation membrane attached to a zirconia substrate.[16] In 2000, even higher membrane performances of α=192~3360 and permeation flux of 0.1~0.2kg/(m^{2}h) in a similar pervaporation using A-type zeolite separation membrane were reported.[17]

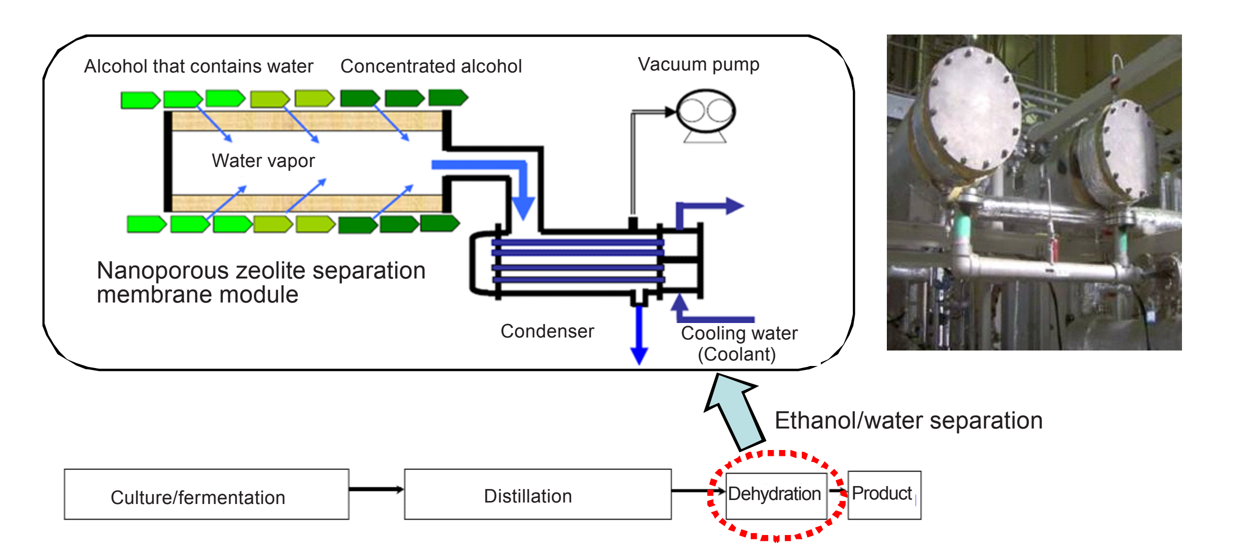


Figure 8 : Nanoporous zeolite separation membrane module for dehydration in the bioethanol fuel refinement pilot plant (in Miyako-jima, Okinawa)

Prepared by the STFC and based on References[5,14,15]

6-3 Dehydration of organic solvent

In the case of the dehydration of organic solvents, such as tetrahydrofuran (THF) and dimethylhydrazine, it is difficult to use polymer separation membrane in general because resistance to organic solvents is required. Therefore, there are high expectations for the application of zeolite separation membrane, and many studies concerning such application have been reported. These include: a study on the dehydration of THF and acetone aqueous solution from industrial wastewater, using Na-A type zeolite separation membrane18]; a study on the comparison of water/THF separation performances of A-type and Y-type zeolite separation membranes, which shows the high selectivity and flux property for Y-type separation membrane19]; and a study on the pervaporation of water/ dimethylhydrazine (95/5wt%) also using Y-type zeolite separation membrane (separation membrane performance of α=52,000, water flux of 3.95kg/(m^2h)).[20]

The process of oxidizing ethylene into ethylene oxide and then hydrolyzing ethylene oxide yields ethylene glycol, which is used as an ingredient in polyethylene terephthalate (PET) for polyester fibers and PET bottles. In this hydrolysis reaction process, a very large amount of water is added in order to raise the selectivity of ethylene oxide to ethylene glycol, so a distillation process is used to remove this excess water. If this distillation process can be replaced with membrane separation, it is expected that a significant amount of energy can be saved in the synthesis process. There is an example of an attempted pervaporation of ethylene glycol aqueous solution (70wt%) using A-type zeolite separation membrane with a separation membrane performance of α=1,177, and a permeation flux of 0.94kg/(m^2h).[21]

7 Overseas Technological Trends in the Practical Use of Separation Module Systems

Currently, research and development on the application of nanoporous separation membranes is being actively implemented in regions such as Europe, the U.S. and Asia as well. In particular, with the spread of biofuels, the development of a separation membrane module for the dehydration of alcohol is nearing the stage of practical use in Germany and Singapore. However, the separation membrane permeation performances in these cases do not exceed the performance already obtained in Japan. Also, problems such as the poor water resistance and acid resistance of A-type zeolite separation membrane are yet to be overcome.

Also, several industries, such as the petroleum refining, petroleum chemistry and diversified chemicals industries, have made suggestions regarding separation membrane applications other than those above. Especially in the U.S., research and development on the introduction of separation membrane technology in all parts of hydrogen production and in the field of biomass usage is being implemented actively through various levels of funding, including state-based funds and funds from combinations of enterprises.

(1) Dehydration technology using A-type zeolite separation membrane

As for the dehydration technology using A-type zeolite separation membrane, technological development is at the completion stage in Inoceramic Inc. (Germany) and Hyflux Ltd. (Singapore). Both companies are now starting marketing activities.[22,23]

(2) Separation membrane technology related to the production of hydrogen and biomass

In the U.S., and especially in Midwestern states, such as Mississippi, a large number of R&D projects related to the biomass complex and technologies for producing hydrogen from biomass are being implemented based on agriculture promotion policies. Funds for these projects are collected from the private sector by the Department of Energy, state governments and universities, and are actively invested by cooperative funds.[24] The development of the practical application of nanoporous separation membranes is implemented as one of the projects using such funds.

8 Future Research Issues and How to Approach Them

8-1 Issues related to the research and development of nanoporous ceramic membranes

In order to more expansively utilize nanoporous ceramic membrane systems, consisting of substances such as zeolite, in the chemical synthesis industry and to successfully save energy, it is essential to first establish the technology to manufacture regularly ordered nanoporous separation membranes that can adapt to various usage environment conditions. More specifically, the research and develop projects described below will be necessary to realize a nanoporous ceramic separation membrane that separates the variety of molecules making up industrial materials and that maintains a highly efficient separation performance.

1) Research and development on a separation membrane component that can control with regularity (ordered regularity control) the shape, composition and nanopore diameter of nanoporous ceramic membranes, and that can meet the required level of both thinness and density.

2) Research and development on a highly porous ceramic support substrate that allows for highly efficient exertion of the molecule identification function (molecule sieving function that selects and causes the molecules to permeate and be separated) of nanoporous ceramic membranes.

3) Development of technology related to the manufacturing process of separation membranes explained above, and realizing a module system using such membranes by fully utilizing low cost chemical processes, such as hydrothermal synthesis.

4) Fundamental research and development related to the analysis and evaluation of separation membrane properties, as well as the analysis and evaluation of regularly ordered nanoporous structure at an atomic level, that supports the research and development mentioned above.

8-2 How to approach future research and development issues

The area of materials in the nanotechnology/materials field that is one of the four priority fields to be promoted in the Third Science and Technology Basic Plan includes research and development for innovative material technology for the highly efficient use of energy. The importance of promoting the innovative energy-saving type of Monozukuri technology as one of the important research and development issues[25] is also pointed out under Monozukuri technology, which is another of the four fields specified for promotion in the Basic Plan. Research and development of the components of nanoporous ceramic membranes, and module systems using them definitely, fall under the categories of these research issues.

In the “Nanotechnology Sector” mentioned in the Strategic Technology Roadmap for FY2008 by the Ministry of Economy, Trade and Industry, the technologies mentioned above are regarded as being related to the “New Material for Separation Processes,” and are categorized under the advanced control of materials/high-order structure control technologies for nanoprocessing. On the other hand,

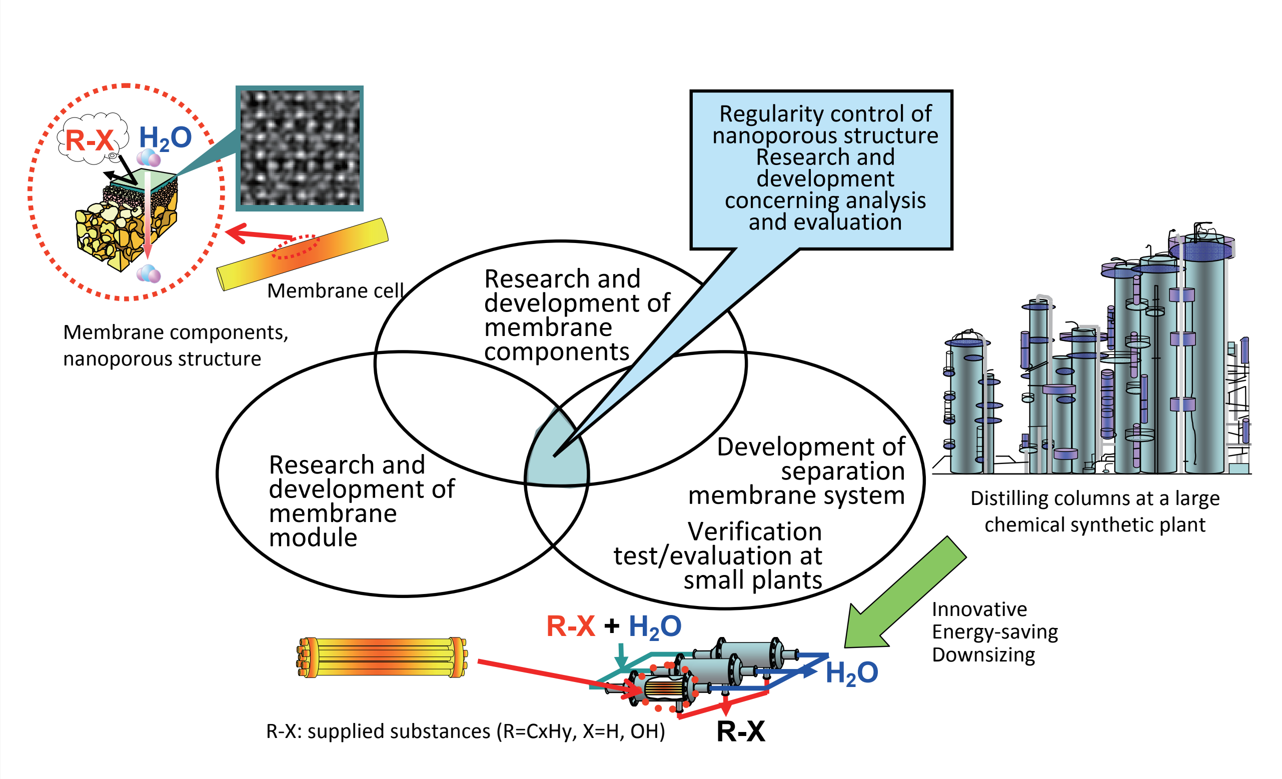


Figure 9 : Research and development topics for the application of nanoporous ceramic separation membranes system in the chemical synthesis process

Prepared by the STFC

in the "Energy Sector," research and development of separation membrane components is categorized under "Advanced Combustion System Technology – Energy-saving in Production Processes – Chemical Materials Process" in the "Technologies Conducive to the Increase of Total Energy Efficiency". At the same time, separation membrane components are also regarded as an individual technology that is expected to contribute largely to the "Increase of Total Energy Efficiency," which is a policy objective.[26]

If a groundbreaking chemical synthesis module system with a small environmental load and a cost performance enabling practical application can be developed through the use of nanoporous ceramic membranes, extensive use in the field of "Monozukuri Technology" can also be expected. As mentioned in Chapter 7, it can be said that separation membrane materials technology in Japan is leading the world in the present circumstances. Japan should continue to lead the rest of the world in this material technology field and establish a technologically superior position compared with other countries. To this end, recommendations regarding future research and development approaches are made as follows.

1) In order to accelerate the research and development of nanoporous separation membrane, it is necessary to identify various fundamental technologies necessary for the practical application of the system, by implementing a research and development structure wherein verification tests at small plants are implemented at the same time as the research and development of membrane materials at stages earlier than the existing materials, and also to clarify and solve accompanying problems.

2) In the immediate future, attention should be focused on using zeolite ceramic materials for separation membranes because such materials have superior heat resistance, chemical resistance and mechanical strength. Doing so will enable the promotion of projects as mentioned in 1) above under a coalition of public research institutes, including universities, and components manufacturers, plant manufactures and chemical synthetic manufacturers.

3) Nanomaterials structure control at the point of separation membrane synthesis, and also the analysis/evaluation thereof, are essential fundamental technologies. The government should focus its investment on

promoting the research and development of such fundamental materials technology. In particular, universities and public institutes should exert their abilities in research and development in this area.

The application of the issues for research and development given above in the chemical synthesis processes are shown schematically in Figure 9. This shows the pattern of research and development conducted by fusing technologies for components, modules and systems through projects that specify clear product objectives for the nanoporous ceramic membrane module system, and by identifying at an early stage practical or commercial problems, including the economic efficiency of the system, through verification tests at small plants. Also, technologies related to the regularly ordered control of nanostructure and the analysis/evaluation thereof are fundamental technologies.

In the past, it took considerable time for the results of industry-academia-government cooperation projects to be put to practical use, and in many cases they could not reach the stage of commercialization. Although an increasing number of projects now realize close cooperation between materials technology and system technology in order to implement research and development, very few of them produce results that are commercialized and put into practical use in the short term after the completion of the project. That is because the solving of various problems at the final commercialization stage, including problems related to the economic efficiency of technologies developed, is not included in these projects' objectives, and the projects have no mechanism for achieving such problem solving.

9 Conclusion

In this article, we discussed trends in research and development regarding the analysis and evaluation of components, the manufacturing process and microscopic structure of nanoporous ceramic membranes, mainly focusing on zeolite materials, as well as the energy-saving effect of membrane separation expected in various chemical synthesis processes.

Japan has been the front runner in research and development of nanoporous ceramic membranes, and some of the achievements of such technologies developed are already starting to be put to practical use, although application is limited to areas such as hydrogen separation and alcohol dehydration. It is expected that more and more separation membrane technologies that can fulfill the needs of various chemical synthesis processes are developed, and a significant reduction in environmental load in the chemical synthesis industry is also achieved. A module system using nanoporous ceramic separation membrane could be a groundbreaking means to allow for significant energy-saving in chemical synthetic plants.

At present, Japan is leading other countries in the research and development of separation membrane technologies. However, an effective way to continue to maintain this technical superiority, is to implement projects wherein research and development on component technologies, and module and system technologies, and research and development on the practical use thereof, are promoted in parallel.

Acknowledgement

Professor Masahiko MATSUKATA of Waseda University provided guidance on the research and development of nanoporous ceramic membranes in general. Senior Research Scientist Yukichi SASAKI of Japan Fine Ceramics Center furnished us with the latest information on the analysis and evaluation of the microscopic structure of nanoporous zeolite separation membrane. We would like to take this opportunity to express our deep gratitude to both of these specialists.

References

[1] General Energy Statistics 2000, compiled by the Agency for Natural Resources and Energy

[2] "Survey on the Energy Saving and Efficiency Raising of Processes Using Inorganic Ordered Nanoporous Thin-Films (FY2006)," Waseda Research Institute (report on the project commissioned from the Ministry of Economy, Trade and Industry, scheduled to be issued in 2009)

[3] FY2006 Report on "Program for New Technologies to Prevent Global Warming – Development of High-Efficient and High-temperature Hydrogen Separation Membrane – ," New Energy and Industrial Technology Development Organization (NEDO)

[4] E. Kikuchi, Catalysis Today, 56, p.97–101 (2000)

[5] FY2006 Report on "Technology Survey on the Energy Saving and Efficiency Raising of Chemical Synthesis Processes Using Membrane Reactors," NEDO

[6] Y. Ono, T. Yashima, "Science and Engineering of Zeolite," Kodansha Scientific (2000)

[7] H. Kita, "Zeolite Membranes for Pervaporation and Vapor Permeation" in Materials Science of Membranes (2006), Wiley, New York, p.373

[8] "Membrane Science Experimental Techniques 1.3, Methods to Manufacture Inorganic Material Membranes," The Membrane Society of Japan (2007)

[9] H. Kita, MEMBRANE, 20, p.169 (1995)

[10] D. M. Bibby and P. Dale, Nature, 317, p.157 (1985)

[11] W. Xu et al., J. Chem. Soc., Chem. Commun., p.755–756 (1990)

[12] M. Matsukata, S. Inagaki, Y. Sekine, E. Kikuchi, Shokubai, 49, p.579–584 (2007)

[13] Y. Sasaki, MEMBRANE, 32, p.347–354 (2007)

[14] K. Okujima, "Presentation Materials for Symposium on the Promotion of the Practical Use of Biomass Fuels" (2006)

[15] Y. Murakami, Rippou to Chousa, No. 281, p.60–68 (2008)

[16] J.J. Jafar and P.M. Budd, Microporous Mater., 12, p.305–311 (1997)

[17] X. Lin, E. Kikuchi, M. Matsukata, Chem. Commun., p.957–958 (2000)

[18] A. Urtiaga, E.D. Gorri, C. Casado, I. Ortiz, Sep. Purif. Technol., 32, p.207–213 (2003)

[19] I. Ortiz, D. Gorri, C. Casado, A. Urtiaga, J. Chem. Technol. Biotech., 80, p.397–405 (2005)

[20] A. Urtiaga, E.D. Gorri, C. Casado, I. Ortiz, Sep. Purif. Technol., 32, p.207–213 (2003)

[21] O.G. Nik, A. Moheb, T. Mohammadi, Chem. Eng. Technol., 29, p.1340–1346 (2006)

[22] http://www.inocermic.de/en/prod_inopor_e.html

[23] http://www.ceparation.com/index.html

[24] NEDO Kaigai (Overseas) Report, No. 1026 (2008)

[25] "The Third Science and Technology Basic Plan; Promotion Strategies for Prioritized Areas," Council for Science and Technology Policy：http://www.Mext.go.jp/a_menu/kagaku/kihon/06032816/001/001.pdf

26] "Strategic Technology Roadmap for FY2008; Energy Sector, Nanotechnology Sector," the Ministry of Economy, Trade and Industry：
http://www.meti.go.jp/policy/economy/gijutsu_kakushin/kenkyu_kaihatu/str2008.html

Profile

Yuji IWAMOTO
Affiliated Fellow,NISTEP
Visiting Research Scientist
Professor, Department of Frontier Materials, Graduate School of Engineering, Nagoya Institute of Technology
Visiting Principal Research Scientist, Japan Fine Ceramics Center

PhD (Science)
He is engaged in the development of the technique for the synthesis of fine ceramic particles, thin films and nanoporous materials through chemical processes using organometallic compounds as a precursor. He is also engaged in application research on using nanoporous materials as a gas separation membrane and a fluorescent substance.

Hiroshi KAWAMOTO
Affiliated Fellow,NISTEP
Leader, Nanotechnology and Materials Research Unit
Principal Research Scientist, National Institute of Science and Technology Policy
http://www.nistep.go.jp/index-j.html

PhD (Engineering). Research Scientist, The Japan Society of Mechanical Engineers. After being in charge of the strength design and evaluation of automotive components at the development stage for Toyota Motor Cooperation, he is now engaged in METI-related projects (including the research and development of fine ceramics) at the Japan Fine Ceramics Center. He majored in the strength design and reliability assessment of structural components.

(Original Japanese version: published in Febrary 2009)

5

Energy Saving Lighting Efficiency Technologies

Yoshihisa TAKEI
Environment and Energy Research Unit

1 Introduction

Beginning with fire, mankind has always exploited a variety of artificial light sources over the centuries. Using these light sources, we are able to do as we please any time and any place with or without sunlight. We can no longer imagine living without artificial lighting (hereafter "lighting") especially since the time that electric lamps first became widely available.

Artificial light sources are inseparably tied to our lives, as lighting for various activities, heat sources for space heating and drying processes, information-processing media such as communication and copy machines, indicators for traffic signal lights and billboards, decorative illumination in scenic spots, and so on. The uses are innumerable.

But are these lights used in an efficient way? Light is a form of energy, and when a light source is turned on, commensurate power consumption always takes place. Since lighting is accomplished mainly by consuming fossil energy, it is imperative to employ efficient lighting.

Japan is obligated to reduce its greenhouse gas emissions with the entry into force of the Kyoto Protocol, but in reality, emissions have increased in comparison with the base year. New measures are required in addition to existing measures, especially for reducing the use of fossil energy. Lighting is a major source of power consumption in Japan, accounting for more than 10 percent of the gross generation. This is an area that requires energy conservation.

Outside Japan, policies banning the use of incandescent light bulbs, which are less efficient than fluorescent lamps, have been promoted as measures for reducing greenhouse gas emissions mainly in Europe and the United States. In Japan, lamp manufacturers have announced that they will stop producing general incandescent light bulbs by 2012 according to the intention of the Ministry of Economy, Trade and Industry. This will accelerate the process of replacing incandescent light bulbs with fluorescent lamps. Research laboratories of manufacturers and universities are developing light-emitting diodes (hereafter "LEDs") for lighting, which are more efficient than fluorescent lamps. Given these circumstances, the Council for Science and Technology addressed high-efficiency lighting systems using new light sources in May 2008 as technologies required for reducing greenhouse gas emissions in its "Environment and Energy Technological Innovation Project".[1]

This report, under the theme of energy-saving lighting methods, will cover the development of energy saving, highly efficient lighting fixtures, and the trends of the most advanced technologies for efficient lighting, which have rarely been examined so far.

2 Present Lighting Situation

2-1 Need for Efficient Lighting

Of a total generation of 988,900 GWh[2] in FY2005 in Japan, 135,500 GWh,[3] or 13.7% of generated electric energy, was consumed for lighting , as shown in Figure 1. Lighting is a relatively large part of our daily lives and lighting-related energy saving is easy for individuals to tackle. The effect of improvements in lighting will be significant because of a large amount of energy consumed for lighting.

While the use of mirrors and light-storage techniques to bring sunlight into buildings can contribute to saving energy, this report focuses on the efficiency

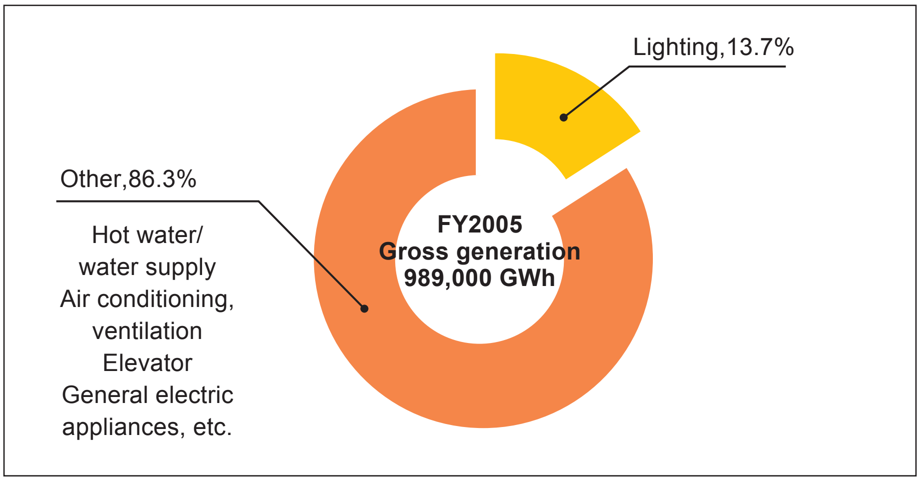


Figure1 : Electricity consumption for lighting in Japan

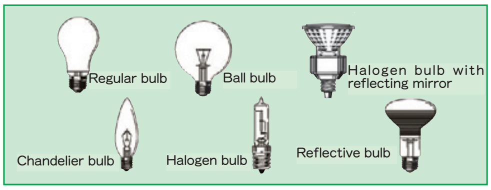
Prepared by the STFC

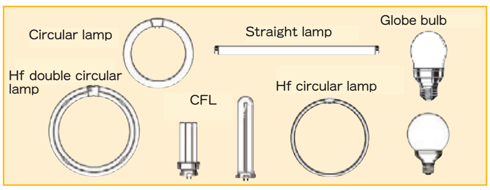
of artificial lighting, which is defined in this report as illumination provided by light energy obtained from electric energy supplied to artificial light sources.

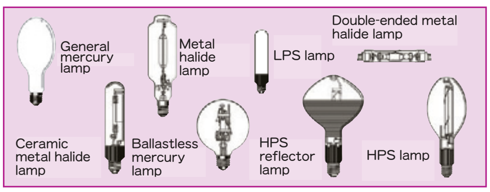
2-2 *Prevalent Light Bulbs*

As shown in Table 1, lamps can be roughly classified into three categories according to their light-emitting principles. Each lamp has advantages and disadvantages in its usage, and is used according to intended purposes. An index called "lamp and auxiliary efficacy" is widely used for comparing these lamps in terms of energy efficiency. The lamp and auxiliary efficacy(lm/W or lumens per watt) is the quotient of the total luminous flux (the total amount of light emitted by a light source in all directions, unit: lm or lumen) divided by the power consumption (unit: watt) of the lighting fixtures that mounts the lamp. As the lamp's total luminous flux is greater, less electricity is consumed for maintaining the same brightness; thus the lamp is more efficient. Table 2 shows the representing lamp and auxiliary efficacy of typical lamps as of FY2005.

Table1 : Electricity consumption for lighting in Japan

<table>
<tr><th colspan="2">Lamp type</th><th>Major usage</th><th colspan="2">Characteristics</th></tr>
<tr><td rowspan="2">Incandescent & halogen bulbs</td><td rowspan="2">

General lighting, ball, chandelier, halogen, etc.</td><td rowspan="2">· Homes
· Commercial facilities
· Amusement facilities</td><td>Advantages</td><td>· Least expensive and convenient.
· Can be directed freely.
· Enhance color.
· Give us comfort.</td></tr>
<tr><td>Disadvantages</td><td>· Short lifespan. (1,000 to 2,000 hours)
· Low efficiency.
· Produce a large amount of heat.</td></tr>
<tr><td rowspan="2">Fluorescent lamps</td><td rowspan="2">

Circular, straight, globe bulb, compact, etc.</td><td rowspan="2">· Homes
· Offices
· Factories
· Commercial facilities</td><td>Advantages</td><td>· Long lifespan. (3,000 to 10,000 hours)
· High efficiency.
· Can produce many different colors of light.</td></tr>
<tr><td>Disadvantages</td><td>· Low tolerance for low temperatures.
· Low tolerance for repeated on and off.</td></tr>
<tr><td rowspan="2">HID lamps</td><td rowspan="2">

Mercury, metal halide, LPS, HPS, etc.</td><td rowspan="2">· Sports facilities
· Roads, tunnels
· Commercial facilities</td><td>Advantages</td><td>· Long lifespan. (6,000 to 12,000 hours)
· High efficiency.
· Small and bright.</td></tr>
<tr><td>Disadvantages</td><td>· Expensive.
· Take about 10 min. to glow.</td></tr>
</table>

The reference[4] was partly modified by STFC

Table 2 : Efficacy of typical lamps (representing values)

Category	Lamp type	lamp and auxiliary efficacy [lm/W]
Incandescent & halogen bubls	Halogen bulb (100W)	16
	Regular incandescent bulb (60W)	14
Fluorescent lamps	Hf fluorescent lamp (45W)	92
	Cool white fluorescent lamp (36W)	77
	Bulb type fluorescent lamp (25W)	61
HID lamps	General HPS lamp (360W)	123
	Metal halide lamp (400W)	90
	Fluorescent mercury lamp (400W)	52

The reference[5] was partly modified by STFC

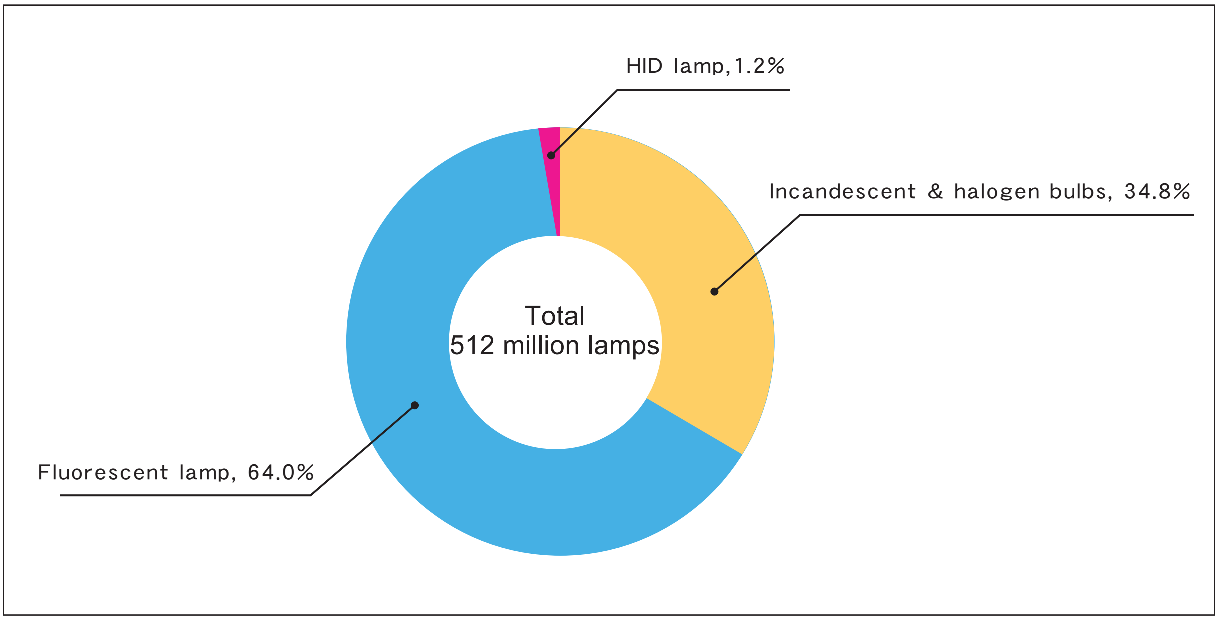


Figure2 : Domestic shipments of lamps and their percentages (FY2005)

Source: Reference [3]

Figure 2 shows the quantity of lamps domestically shipped in FY2005. Approximately 500 million lamps were shipped in this fiscal year, of which fluorescent lamps accounted for the largest share followed by incandescent and halogen bulbs, and HID lamps (in this order). As shown in Table 2, energy can be saved simply by replacing incandescent bulbs with fluorescent lamps because of a significant difference in efficiency between these lamps; but unlike the countries where incandescent bulbs are more popular than fluorescent lamps, the proportion of fluorescent lamps to incandescent bulbs is about two to one in Japan. Since fluorescent lamps have already been widely used, efficient lighting alone won't save much energy. More efficient lighting systems also need to be developed to achieve meaningful energy saving.

3 Measures for Efficient Lighting Systems

The two measures explained below can be taken to increase efficiency in lighting systems.

(1) Improving the efficiency of lighting fixtures

The same amount of light can be emitted with less electricity consumption by improving the efficiency of lighting fixtures. The efficiency of lighting products has been continuously improved one after another by improving the lamp itself and lighting circuit, but the efficiency of existing products in both lamp and circuit will soon reach its maximum. Consequently, new light sources that have much higher efficiency (such as LEDs) than lighting fixtures using conventional lamps, are being exploited.

(2) Improving the efficiency of lighting methods

By lighting a required area at a required level of brightness, efficient lighting can be achieved. This mainly applies to indoor lighting. This kind of approach has rarely been examined so far, but allows us to save energy regardless of the types of lighting fixtures used.

3-1 Existing Lighting Fixtures with Improved Efficiency

3-1-1 Incandescent and Halogen Bulbs

Incandescent light bulbs, developed in the 19th Century, have the longest history of the electric lights. Despite a high rate of loss as heat energy and inefficiency, these light bulbs are still widely used mainly in commercial facilities because of their warm color tone. In contrast, regular incandescent bulbs that can be replaced with fluorescent lamps will disappear before too long as lamp manufacturers decided to stop producing them by 2012.

Replacement with fluorescent lamps is difficult for special bulbs such as Krypton and halogen bulbs, which are characterized by their compactness and attractiveness as effective lighting with high color rendition. Production of these lamps will, therefore, be continued, but there is a desire for alternatives with enhanced color rending properties comparable to special bulbs so that energy saving can also be achieved in this field, though the ratio of special bulbs to all lamps is small and contribution to overall energy saving is also small.

3-1-2 Fluorescent Lamps

As shown in Figure 2, fluorescent lamps account for over 60 percent of the total quantity of lamps shipped in the fiscal year. These lamps are the most popular lamps in Japan. When the fluorescent lamp was invented in the 20th Century, only straight tubes were immediately available, then circular tubes, and more recently, globe bulbs were developed. Now, suitably shaped fluorescent lamps are available depending on the place of use. Because of high efficiency and long lifespan, fluorescent light fixtures have become widely used in Japan. The turning point was the oil shock in the 1970s.

Efficiency technologies have been actively developed for fluorescent lamps. Both lamps and lighting circuits, including ballasts, have been improved, and inverter-type ballasts and inverter-specific Hf fluorescent lamps (fluorescent lamps driven exclusively by a high frequency), which can reduce losses that do not contribute to light emission, have led to considerable improvement in efficiency.

Fluorescent lamps, which were developed to replace conventional regular incandescent bulbs, are globe bulb-type fluorescent lamps. These lamps are provided with a built-in lighting circuit or ballast and can be screwed into a conventional socket for incandescent bulbs. Globe bulbs have a luminous efficiency that is four times higher than that of incandescent bulbs, reducing power consumption to 1/4 of the conventional bulbs when providing the same amount of light. This means that the energy-saving effects would be significant if incandescent bulbs were simply replaced by fluorescent lamps. As the cost of producing fluorescent lamps has been

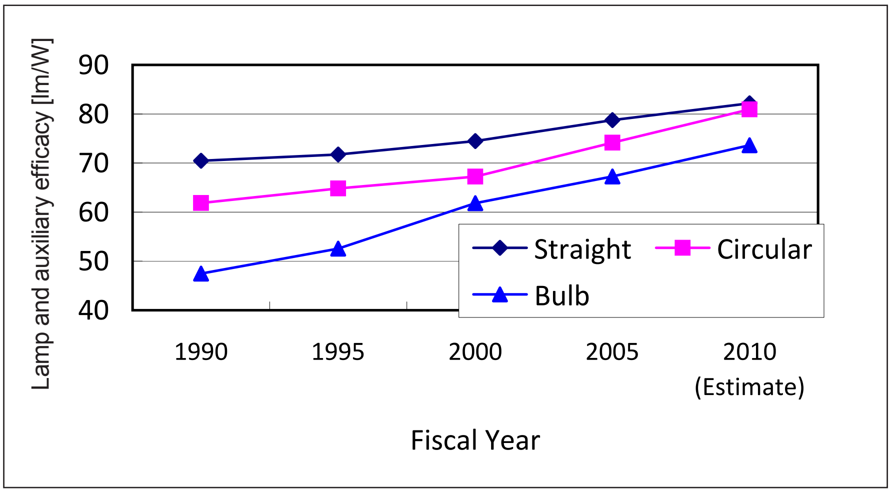


Figure3 : Changes in mean efficacy of fluorescent lamps

Source: Reference [3]

considerably reduced, introduction of these lamps can be accelerated in a short period.

Figure 3 shows changes in the mean efficacy of fluorescent lamps. The efficiency of each lamp has increased every year, and the efficiency of straight and circular lamps is particularly significant as inverter-type Hf fluorescent lamps have been disseminated.

Fluorescent lamps are the most popular lighting fixtures in Japan at present, but mercury contained in the tube is difficult to process after the lamps are discarded. There are companies that collect mercury from discarded fluorescent lamps, but only a fraction of lamps are brought to these companies, and many municipalities still collect and dispose of them in landfills as non-burnable garbage. The efforts to improve fluorescent lamps have reduced the amount of mercury; for example, fluorescent lamps manufactured in 2007 contain less than 10 mg of mercury compared with those manufactured in 1980[6] containing 100 mg of mercury, but still a certain time is required to achieve zero mercury. Establishment of a collection system is a big issue to be solved.

3-1-3 HID (High Intensity Discharge) Lamps

High-pressure mercury lamps, metal halide lamps and high-pressure sodium lamps are generically called high intensity discharge lamps. These lamps are highly efficient, suitable for illuminating a wide area continuously for a certain period time, and widely used in factories, gymnasiums and roads.

Metal halide lamps were developed for the purpose of increasing the efficiency and color-rendering properties of mercury lamps used often for large-scale outside lighting. Replacing mercury lamps with metal halide lamps has been gradually promoted, but the proportion of HID lamps to all lamps is still small. The lamps also have the same mercury-treatment problem at the time of disposal.

3-2 Energy Saving Effects of Higher Efficiency Alternatives

The Japan Electric Lamp Manufacturers Association (JELMA) has recommended four energy-saving measures[4] through which existing lamps are to be replaced with more efficient alternatives. As a result, the power consumption can be reduced by a maximum of 12,740 GWh. According to the estimation by the JELMA, power consumption in 2010 will be 138,000 GWh if none of these measures are taken. In contrast, if all of measures (a) to (d) are implemented, a large reduction equivalent to 9.2% of all power consumption can be achieved.

(a) Replace regular incandescent bulbs with highly efficient fluorescent lamps (assuming that half of bulbs can be replaced).

(b) Replace halogen bulbs with more efficient lamps (assuming that half of lamps can be replaced, and the proportion of conventional lamps to alternatives is 1 to 1).

(c) Replace all 40W straight fluorescent tubes, which are most widely used among all fluorescent lamps, with Hf fluorescent lamps.

(d) Replace all mercury lamps with metal halide lamps.

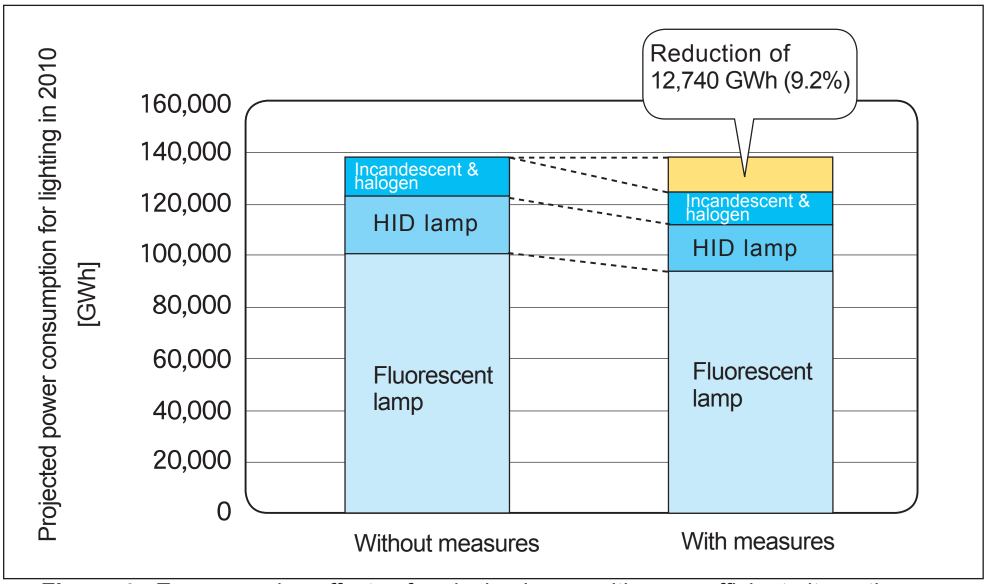


Figure 4 : Energy-saving effects of replacing lamps with more efficient alternatives

Prepared by the STFC based on Reference[4]

The efficiency of light bulbs, including fluorescent lamps, has steadily been improved, and will be continuously improved by lamp manufacturers. However, efficiency improvements have a limit. It is unrealistic to expect a significant improvement, for example, to 200 lm/W, which is twice the present level. Consequently, alternative new light sources have been exploited.

3-3 Development of Lighting Fixtures Using New Light Sources

3-3-1 Development of LED Lighting Fixtures

LEDs are a semiconductor. They emit light when electric current passes through them. They are expected to be a next generation light source possibly having a luminous efficiency of 200 lm/W (as a light source, not a lighting fixture), which is considered difficult to achieve with traditional light sources. Since light is emitted from the semiconductor component itself, LEDs contain few deteriorating parts and have longer lifespans than traditional light sources. LED chips (semiconductors without circuits) with a luminous efficiency of 150 lm/W have already been achieved. In reality, however, the efficiency sharply drops when the semiconductor is assembled into a fixture. Enhanced lamp efficacy is the present issue. Losses in conversion from AC to DC power (LEDs require direct current to operate) and heat from peripheral devices (reduction due to heat) are said to be potential causes for the drop in efficiency.

LED lamps emit pale blue light, which is not suitable as an alternative to incandescent bulbs or fluorescent lamps. The development of a product that can emit light similar to the one emitted from incandescent bulbs is desired. Decreases in color temperatures are detrimental to efficiency. Further increases in efficiency are considered urgent necessities to replace existing products.

Figure 5 shows the projected improvements in the lamp and auxiliary efficacy of LED lighting fixtures presented by NPO, the Japan LED Association. The products emitting warm white light (incandescent color) are intended to replace incandescent bulbs and fluorescent lamps. Their luminous efficiency has already exceeded incandescent bulbs to a considerable extent, but is about the same level with fluorescent lamps. The efficiency of warm white light emitting LED lighting fixtures is expected to be improved every year, and may exceed fluorescent lamps within a couple of years. It is also expected to overtake metal halide lamps, a typical HID lamps, and currently most efficient fluorescent lamp, Hr tubes around 2015.

In order to show the possible effects of introducing LED light fixtures quantitatively, the projected maximum values based on the assumptions of (a) to (c) are listed in Figure 6.

(a) Required scale of lighting

The required scale of overall lighting is fixed. The total amount of luminous flux (the sum of the amount of light emitted by a lighting fixture) in 2010, estimated by the Japan Electric Lamp Manufacturers Association, is assumed to be the required amount of luminous flux in each fiscal year. The power consumption in 2010 is the result of "With measures" in Figure 4.

(b) Efficiency of LED lighting fixtures

The efficiency is based on the technology roadmap in Figure 5, prepared by NPO, the Japan LED

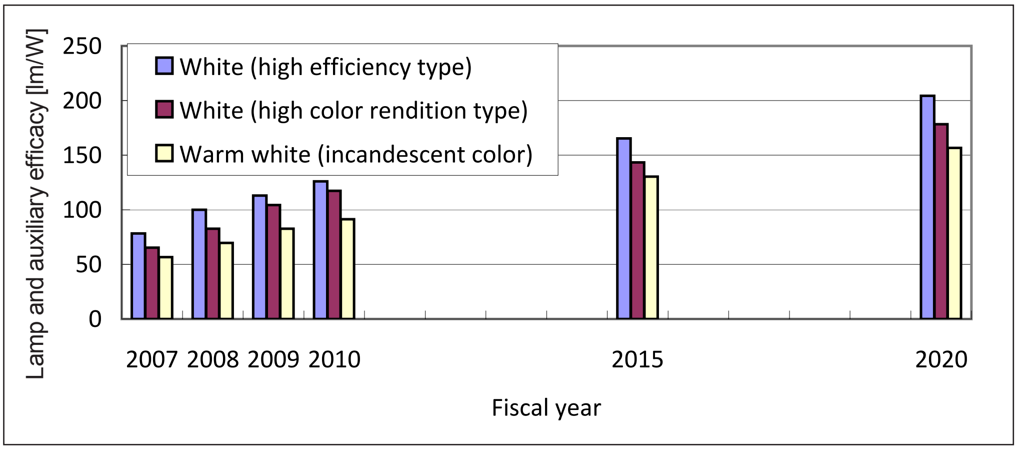


Figure 5 : Projected improvements in the lamp and auxiliary efficacy of LED lighting fixtures

Prepared by the STFC based on Reference[7]

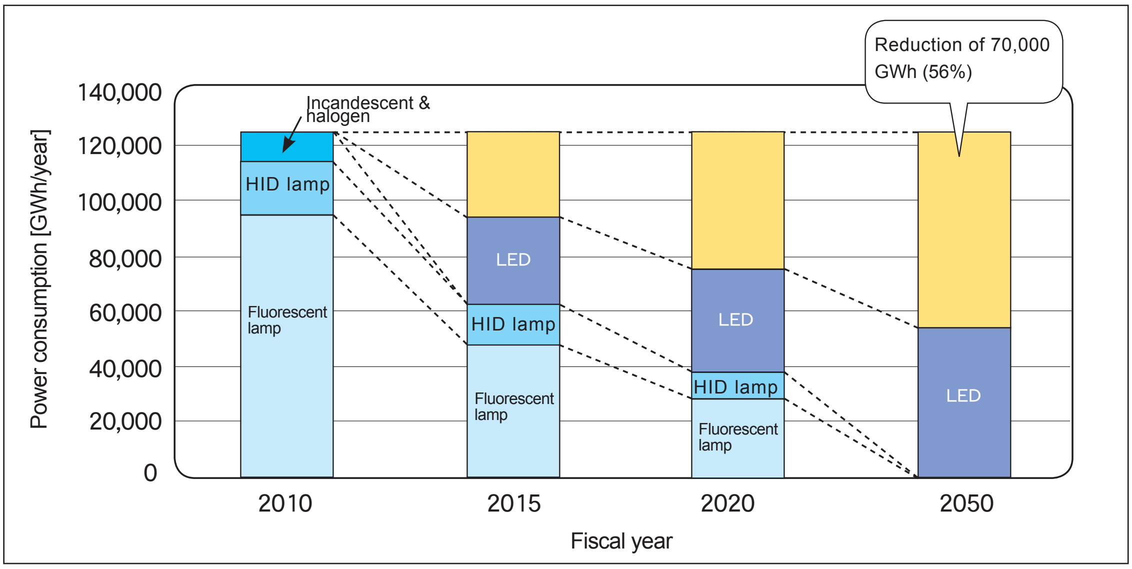


Figure 6 : Energy-saving effects of replacement with LEDs (possibility)

Prepared by the STFC

Association. The value in 2020 is also used for the efficiency in 2050, which is excluded from estimation.

(c) Progress of replacing existing lighting fixtures with LEDs

It is presumed that LEDs will replace all incandescent and halogen light bulbs by 2015, while gradually replacing other lamps. All existing lamps will be replaced with LEDs in 2050. This is, in short, a presumption for estimating the maximum effects. Figure 6 shows the estimated effects of introducing LEDs based on the above assumptions. There is a large possibility of halving the present power consumption. As indicated above, LEDs are a markedly effective technology for saving energy through lighting, but there are also a number of technical issues to be solved for the dissemination of LEDs in the future.

The energy-saving effects that were discussed heretofore focused only on efficiency, but the dissemination of LEDs is not possible if it is not economically viable. Reducing the product cost is therefore a large issue. The present price of LED lighting fixtures is four to five times the price of fluorescent lamps. Though the initial investment is high compared with bulb-type fluorescent lamps, the price of high efficiency LEDs has already been set to a level allowing the initial investment to be paid off in five to six years[8]. Reduced product cost is desirable in order to maximize the advantages of introduction.

To replace the existing products, the performance of LEDs should be at least equivalent to that of these products, not to speak of efficiency. Since the warm light of incandescent and halogen lamps is a preferred color of light, LEDs with the incandescent color are being developed as in the case of fluorescent lamps. While it is under development now, the quality of light and variety of products must be provided for the satisfaction of consumers.

Because the history of LEDs as commercial products is short, standards have not yet been established. Standards are necessary since more manufacturers are expected to break into the market with increased demand for LEDs.

3-3-2 Development of OELD Lighting Fixtures

OLED lighting fixtures are developed as a next generation light source of LEDs. Advantageous features of OLED include[9] the following:

- A light-emitting plane is formed with light-emitting compounds deposited on the surface of a substrate. The very thin light emitting plane allows the entire fixture to be thin. The fixture can also be bent flexibly if flexible materials are used for the substrate.
- A luminous efficiency of 200 lm/W is theoretically attainable according to calculation. Light of any color can be emitted by combining various light-emitting compounds.

As listed above, the features of OLED are quite different from those of other light sources, including LEDs. In addition to the replacement of conventional lighting fixtures, it can be used in totally different applications, for example, for toothbrushes, dental mirrors, magnifying lenses and bags, and other items on which lights could not be installed so far.

At present, the lamp and auxiliary efficacy of OLED is 20 lm/W, which is almost the same as that of incandescent bulbs, and the lifespan is 3,000 hours, which is less than half the lifespan of fluorescent lamps. Because of these figures, it remains in the trial phase. However, a roadmap for catching up with LEDs was drawn up concerning the lamp and auxiliary efficacyof OLED, as shown in Figure 7. Commercialization of OLED as a lighting fixture is promoted along with the extension of the lifetime of elements. If the efficiency and lifespan of OLED bear comparison with those of LEDs, OLED will be used more widely because of its property that light of any color can be emitted.

3-4 *Efficient Lighting Methods*

3-4-1 Changes in Power Consumption in Lighting

As explained in 3-2, the efficiency of lighting fixtures has been largely improved. This section will verify that the improved efficiency contributes to saving energy based on data accumulated so far.

Figure 8 shows changes in the total power consumption and luminous efficiency of lamps summarized by the Japan Electric Lamp Manufacturers Association. The power consumption from 1990 to 2010 was nearly uniform in a range between 130,000 and 140,000 GWh, while the mean luminous efficiency (a weighted average of all lamps used in Japan) has increased every year during this

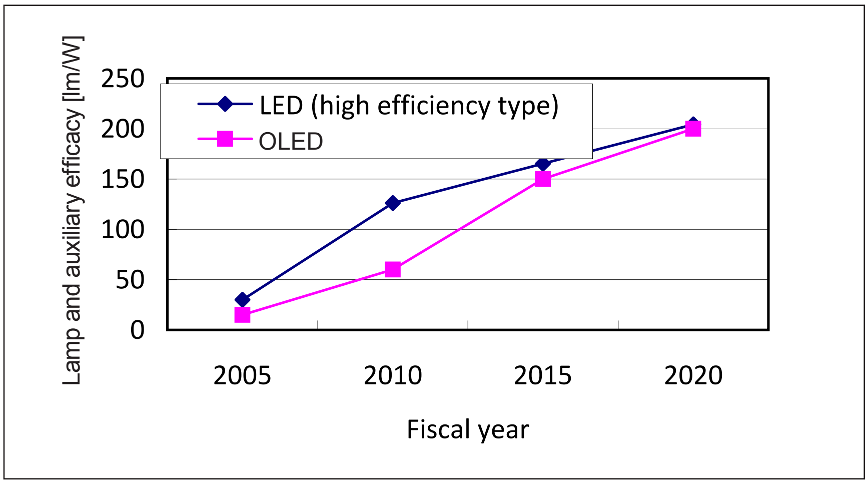


Figure 7 : Projected improvements in the lamp and auxiliary efficacy of OLED lighting fixtures (comparison with LEDs)

The reference[4] was partly modified by STFC

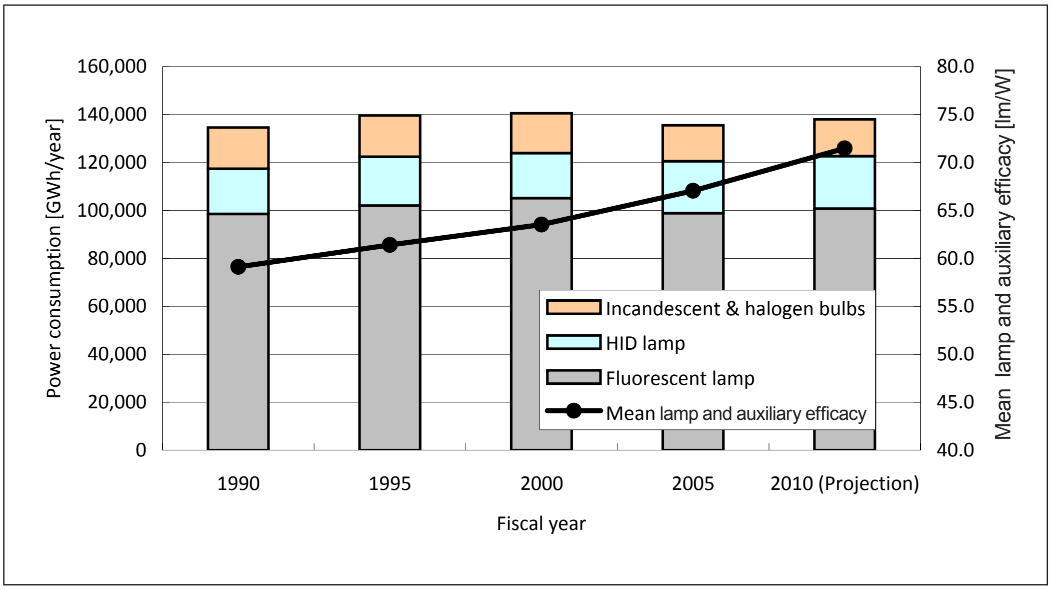


Figure 8 : Changes in total power consumption and mean efficacy of lamps

The reference[4] was partly modified by STFC

period.

In principle, the total power consumption should have decreased each year with improved efficiency if the same brightness was maintained. Assuming that the brightness of 1990 was maintained as the satisfactory light level throughout the remaining years, energy could have been saved by more than 10 percent since the efficiency in 2005 was improved by more than 10 percent from the 1990 level, but the result is on the contrary, suggesting the presence of unnoticed factors or potential room for improvement.

We used to think that lights should always illuminate brightly to make the environment comfortable and increase work efficiency. In contemporary offices, this is not necessarily true partly because the volume of work with computers is increasing. Adjusting lights to the least necessary brightness will also contribute to energy conservation. Therefore, the lighting methods explained below and improvements of their efficiency have been examined.

3-4-2 Task-Ambient Lighting

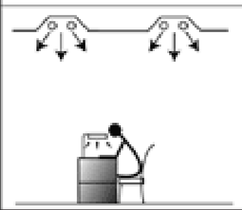
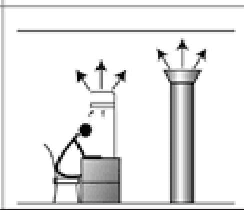
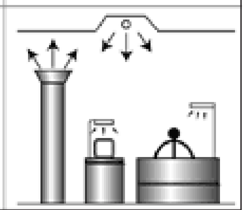
Task-ambient lighting refers to a lighting arrangement in which local task lights are installed separately from ambient lights. While the traditional lighting arrangement provides uniform and direct lighting to keep the entire office bright, day and night, this approach provides higher light levels for the task areas only, for example, on desks that are fixed work areas. Ceiling lights function as ambient lights for creating a good ambient atmosphere, and task lights ensure the brightness of the desk area for work. Table 3 lists schematic diagrams of task-ambient lighting.

This approach saves energy for lighting. Reduced power supply to ceiling lights will reduce heat radiated from these lights, and increase space-cooling efficiency. There is a report[10] of 30-percent decreases in power consumption through the introduction of task-ambient lighting, and additional 15-percent decreases in power consumption for air-conditioning as a result of reduced radiation of heat from lighting facilities. In this manner, a secondary effect can be expected by improving efficiency in lighting methods. In the schematic diagrams in Table 3, workers are able to adjust the brightness of task lights only by turning them on and off. A system in which ambient lights can be adjusted invariably is being developed[11] at a university research laboratory for information-processing study from the perspective that every one has a favorite brightness level. This method aims to increase the amenity of workers in offices and improve work efficiency in a similar manner as distributed multiple lighting, which is explained in the next paragraph. Additional increases in efficiency by 20 percent were observed in experiments, making a maximum of 50-percent decrease in power consumption. Task-ambient lighting is an efficient lighting method with the potential for a great energy-saving effect.

3-4-3 Distributed Multiple Lighting

Distributed multiple lighting is a lighting arrangement in which a multiple number of low-watt light fixtures are distributed and separately used depending on the purpose. A typical house has a set of circular fluorescent lamps in the ceiling of the living room and another set of lighting near the dining table. In the left photo of Figure 9, for example, two sets of lamps in the room illuminate at a total of 92 watts. The suitable brightness of lighting fundamentally depends on the activity, number of people in the room, time zones (evening or midnight), purpose (reading a

Table 3 : Schematic diagrams of task-ambient lighting

Mode	TAL (1)	TAL (2)	TAL (3)
Task lighting	Task lights	Task lights	Task lights
Ambient lighting	Overall lighting	Upper lights	Combined TAL (1) and TAL (2)
Schematic view			

* TAL (Task and Ambient Lighting)

Source: Reference[12]

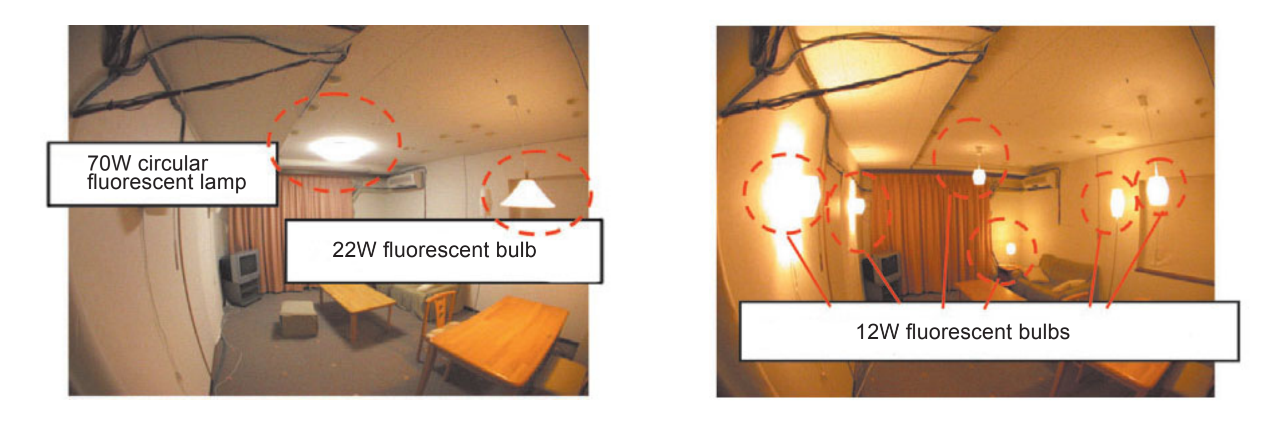


Figure 9 : An example of distributed multiple lighting (left: before; right: after)

Source: Reference[13]

book or chatting) and so on, but it is difficult to adjust brightness with the traditional lighting arrangement. It is said that staying in a bright room at night may result in a disruption of the genuine rhythm of daily lives, and affects the quality of sleep.

The lighting of a household with elderly people tends to be unnecessarily bright, but brightness is required only in the area of work. Illuminating the entire room is not always essential.

In distributed multiple lighting, a multiple number of lights are provided in a room, and used separately depending on the area and time of activity in the room to improve the lighting efficiency. In the right photo of Figure 9, six 12W fluorescent lamps are installed, and even when all lights are turned on, the sum of wattage is 72 watts. The principle of improvement is that total wattage does not exceed that of original one-lamp-per-room arrangement.

This method has been developed to make the living space comfortable by adjusting brightness, and is now expected to save energy too.

3-4-4 Introduction of Human Detection Sensor and Light Control System

Human detection sensors are used for turning on and off designated lights to get rid of wasted electricity caused by forgotten lights. Applications are expanded to the entrance light of a house and the light for emergency staircases in offices. The sensors are becoming familiar to us.

The light control system automatically adjusts the intensity of indoor lights when the sunlight has reached the room. Several systems have already been put into the market. They are useful in that too bright lights can be controlled. This system has been employed in only a limited number of buildings.

4 Future Issues on Diffusion of Efficient Lighting

4-1 Development and Promotion of Highly Efficient Lighting Fixtures for Diffusion

The long-term goal is to improve the efficiency of all lighting fixtures; and in the short term, the prime task is to replace inefficient incandescent and halogen bulbs immediately. For this purpose, compact fluorescent bulbs and other alternatives to incandescent and halogen bulbs are to be developed. Diffusion and promotion of alternatives in a country where preference for incandescent bulbs is stronger than in Japan will contribute to global energy saving. LEDs and OLED were presented in 3-3 as highly efficient alternatives to conventional lighting fixtures. LEDs in particular can be the next generation lighting fixtures, and are likely to be available for saving a large amount of energy when the efficiency indicated in the technology roadmap is achieved.

4-2 Collection and Publication of Data

Efficient lighting is one achievable energy-saving effort in households, but there is only a limited amount of published data on power consumption for lighting. Continuous surveys on power consumption in households are necessary for increasing the awareness of citizens and keeping them informed.

4-3 Establishment of Legislation

4-3-1 Revised Act on the Rational Use of Energy

The Act on the Rational Use of Energy was enacted as an energy-conservation law. The act has been in operation for nearly 30 years, since its establishment in 1979, and largely contributed to saving energy in Japan. Provisions for lighting facilities are included in the act, but only applicable to specific buildings that have a total floor space of more than 2,000 m^2. The scope should be expanded to other existing buildings to increase energy-saving effects.

Qualification systems for persons in charge of energy management are also provided to promote energy conservation. Qualified persons for lighting are also required to exclusively improve lighting efficiency in the future.

4-3-2 Subsidies

Energy-saving technologies have been developed for lighting, including LED lighting fixtures and highly efficient lighting methods. Cost reductions are also discussed. A high initial cost may be inevitable. Subsidies are also necessary in the lighting industry to encourage the use of high-efficiency lighting fixtures to disseminate new technologies, as in the precedent for introducing energy-saving technologies.

Efficient lighting methods are studied mainly at research organizations of universities. To establish the technologies developed in laboratories, demonstration experiments are indispensable for a certain period in a building of a suitable scale. Financial aid at the experimental stage, not at the introduction stage for the completed technologies, is necessary and effective for promoting efficiency-improvement studies for lighting methods.

4-3-3 Review of Standards

Required illuminance in office lighting design is specified to 500 lux[8]. This illuminance should be maintained even if lamps have deteriorated. The initial illuminance of lights is, therefore, set to 700 lux at the time of installation, but this may be an excessive margin of safety ratio surpassing as much as 40 percent of the originally required illuminance.

The illuminance standards[14] were established in 1979. The current computer-based work was not assumed at that time. Required illuminance should be reviewed to make necessary amendments to the standards for adjusting to the present energy-saving requirements.

4-4 Fostering Lighting Engineers

Efficient lighting methods, such as task-ambient lighting and distributed multiple lighting, need to be understood and employed by the client when building facilities are designed. This in turn requires engineers who are familiar with these efficient lighting methods to support the design of facilities.

Lighting engineers should be educated in an integrated manner, and qualified in a qualification system. The Illuminating Engineering Institute of Japan has set an independent training program for engineers, and gives appellations such as lighting consultant and lighting engineer to those who pass the exams. They are, however, less well known to the public. In order to allow lighting engineers to become engaged in design more actively, the authority of engineers should be strengthened. As explained in 4-3-1, legal arrangements, such as national qualification of lighting engineers, are required.

A system of qualifying architects and other appellations in relation to buildings has already been established. Adding lighting engineers to the present qualification system may allow design engineers to obtain lighting technologies.

4-5 Maintaining Japan's Technological Competitiveness in Lighting

Energy conservation in lighting has been achieved in Japan through the use of efficient lighting fixtures. Efforts of lamp manufacturers for technological innovations, including inverter-driven fluorescent lamps, are the major contributing factor. The technologies in Japan take a leading role in the industry for developing new light sources such as LEDs and OLED.

As shown above, Japan is good at developing highly value-added items, but development and production technologies should be continuously refined. Appealing our technological capabilities to the world is also required.

5 Conclusion

Energy consumption is an indispensable part of our modern lives, and this report looks at ways to consume less energy through lighting. As required technologies for the efficient use of efficient instruments are common to all energy equipment and systems, energy conservation should be considered not in one particular case but in every case by understanding the present situation; and it should be carried out under the most optimum conditions. The need for energy-saving efforts never ends, even when some targets are achieved, but should be continued towards the “zero waste” goal.

Acknowledgement

I would like to use this space to thank Dr. Yoshihiko Otani of the College of Industrial Technology, Nihon University, Dr. Sueko Kanaya of the Department of Environmental and Urban Design, Kanazawa Institute of Technology, Mr. Sumio Shimode, chairman of the Planning and Operating Committee, Japan LED Association, an NPO, Dr. Mitsunori Miki of the Department of Science and Engineering, Doshisha University, and Mr. Atsushi Honda, manager of the M&E Engineering Dept., Nikken Sekkei Ltd. for their useful and valuable advice in writing this report.

References

[1] Council for Science and Technology, “Environment and Energy Innovation Project” (2008)
[2] The Federation of Electric Power Companies of Japan, “Information Plaza of Electricity”：http://www.fepc.or.jp/english/index.html
[3] Japan Electric Lamp Manufacturers Association, “JELMA’s Proposal for Energy Saving” (for General Lighting) (2006)
[4] Japan Electric Lamp Manufacturers Association, “JELMA’s Proposal for Energy Saving” (for General Lighting) (2007)
[5] Kotaro Kawamoto and Yoshiki Nakamura, “Energy-saving lighting technology” (2005), Energy Conservation Center, Japan
[6] Robin Devonshire, “Environmental Pressures on Lighting: How is the Technology Responding?” Matsushita Technical Journal, Vol. 53, No. 2, 36-41 (2008)
[7] Japan LED Association, “Roadmap for white LEDs”
[8] Panasonic Electric Works Co., Ltd., LED Lighting Device Catalog, pp 29
[9] Research Institute for Organic Electronics, “Roadmap for OLED lighting development,”：http://www.organic- electronics.jp/
[10] Kajima Corporation, KaTRI leaflet, “Office energy saving techniques” (September 2000)
[11] Mitsunori Miki, Kazuhiro Goto and Tomoyuki Hiroyasu, “A centrally controlled intelligent lighting system,” Proceeding of Annual Conference of the Illuminating Engineering Institute of Japan (2006)
[12] Illuminating Engineering Institute of Japan, “Glossary”: http://www.ieij.or.jp/what/yougo.html
[13] Yasuhiro Miki, “Improving Residential Lighting while Conserving Energy by Distributing High-efficiency Lamps,” National Institute for Land and Infrastructure Management, Annual Report (2005) pp 84–85
[14] Japanese Industrial Standards Committee, JIS Z9110-1979

Profile

Yoshihisa TAKEI
Fellow, Science and Technology Foresight Center,
Environment and Energy Research Unit
http://www.nistep.go.jp/index-j.html

Having engaged in the management of oil- refining facilities, operation of oil-stockpiling bases, and development of new businesses, etc. in an oil company, he is now interested in science, technology and policies for achieving a low-carbon society in the environment and energy fields, and engaged in researches in these fields.

(Original Japanese version: published in January 2009)

6

Trends of Technology for Observing and Forecasting Localized Rains

Eiichi Shiraishi
Monozukuri, Infrastructure and Frontier Research Unit

1 Introduction

The U.N. Intergovernmental Panel on Climate Change (IPCC) published its Fourth Assessment Report in 2007, concluding that warming of the earth's climate system is unequivocal, as is now evident from observation data on all continents and most oceans. Most of the global warming is very likely due to anthropogenic greenhouse gas increases, it says. With current climate change mitigation policies and related sustainable development practices, global GHG emissions will continue to grow over the next few decades, the report notes. Continued GHG emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would very likely be larger than those observed during the 20th century, it says, warning that anthropogenic warming and sea level rises would continue for centuries even if all GHG emissions are stabilized. (http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf)

The report also says the frequency of heavy precipitation events has increased substantially on climate changes caused by the global warming1]. The number of short-lived heavy rain events with an hourly precipitation of 50 mm or more has been increasing in Japan, although the increase indicated by data for the limited period of 30 years in Japan cannot necessarily be attributed to global warming. In such events, rains grow heavier so fast that fast-flowing urban rivers and narrower, shorter ones swell rapidly and cause heavy disasters. For example, the Toga River in Kobe, Hyogo Prefecture, swelled rapidly and caused a flood disaster in 2008. In Toshima Ward in Tokyo in the same year, water quickly increased in sewage pipes, bringing about a flood disaster. Localized heavy rains may increase water in sewage facilities beyond their capacity, causing flood damage on subways or underground malls. Flood damage on such underground facilities has grown likelier. In order to provide warnings about these kinds of large-scale flood disasters, the Central Disaster Prevention Council announced a report on January 23, 2009, predicting that if a heavy flood that may come once in 200 years hits the Arakawa River, which flows through Saitama and Tokyo Prefectures, and destroys the right bank of the river, many subway lines in central Tokyo may be swamped.[2]

Weather factors that cause heavy rains include typhoons, atmospheric depressions, rainy season fronts and autumn rain fronts. This report discusses technology for observing and forecasting localized heavy rains brought by cumulonimbus clouds accompanying summer fronts. Cumulonimbus clouds are also accompanied by lightning. For lightning disasters, see “Anti-lightning Measures That Should Not Be Forgotten for Building Safe, Secure Society,” Science and Technology Trend Journal, April 2007.

2 Features of Rains over Recent Years

Regarding global rainfall changes, the JMA Meteorological Research Institute’s “Basic Knowledge about Global Warming” says precipitation on heavy-rain days (the annual top 5% of heaviest-rain days) has tended to increase its share of total annual precipitation in many onshore regions for which observation data have been available for some 50 years. The tendency has grown clearer over recent years. The book also says that heavy rains have grown more frequent in regions where total precipitation has declined.[3]

Precipitation in Japan also features the increasing frequency of localized heavy rains. Figure 1 indicates the annual number of heavy rain events with an hourly precipitation of 50 mm or more as observed by the Automated Meteorological Data Acquisition System (AMEDAS). The number of AMEDAS observation points in Japan increased from about 1,100 in 1976 to 1,300 in 1979. In order to exclude the impact of changes in the number of observation points, Figure 1 shows the annual number of heavy rain events for 1,000 points. From the 1976–87 decade to the 1998–2007 decade, the frequency of heavy rains increased some 1.5-fold. According to the JMA's rainfall intensity classification, the hourly precipitation of 50 mm represents very heavy rains that could cause many disasters by drowning basements and underground malls in urban regions.

Figure 2 indicates major meteorological observation points that rewrote maximum hourly precipitation records between January 1 and August 31, 2008. This shows that heavy rains occurred at various points throughout Japan. On August 5, 2008, for example, localized heavy rains accompanied by lightning hit Tokyo from the late morning. In Toshima Ward, five sewer workers were washed away through sewage pipes and killed. Weather conditions at that time follow: In the Kanto Region on August 5, a front stayed with a moist south wind, destabilizing the atmosphere. Cumulonimbus clouds emerged at various points in the Kanto Region. Cumulonimbus clouds came out in the western part of Tokyo's 23 special wards in the late morning and moved northwestward while growing larger. Later, many cumulonimbus clouds moved northward from the south, bringing about heavy rains in the western part of the 23 special wards and the southern part of Tama, as indicated by Figure 3[6]. Cumulonimbus clouds come out when air is heated on the ground or cold air exists in the sky near a front. The heavy rains came from cumulonimbus clouds emerging near the front as explained above. Figure 4 is a weather camera picture at noon on August 5.

The JMA gave the following explanations about localized heavy rains observed at various points in Japan between late July and early September 2008: Westerlies that usually blow over Siberia snaked southward to the Japanese Archipelago and brought about cold air over Japan, while a warm-moist air current came from eastern waters into the lower layer of the atmosphere over the main Japanese island. Then, the atmosphere over the main island was destabilized. Well-developed cumulonimbus clouds then came out and brought localized, short-lived heavy rains. A research finding says westerlies tend to snake in East Asia in summer after higher spring temperatures in Eastern Siberia. This phenomenon might have emerged in the period.[8]

Table 1 indicates major losses from localized heavy

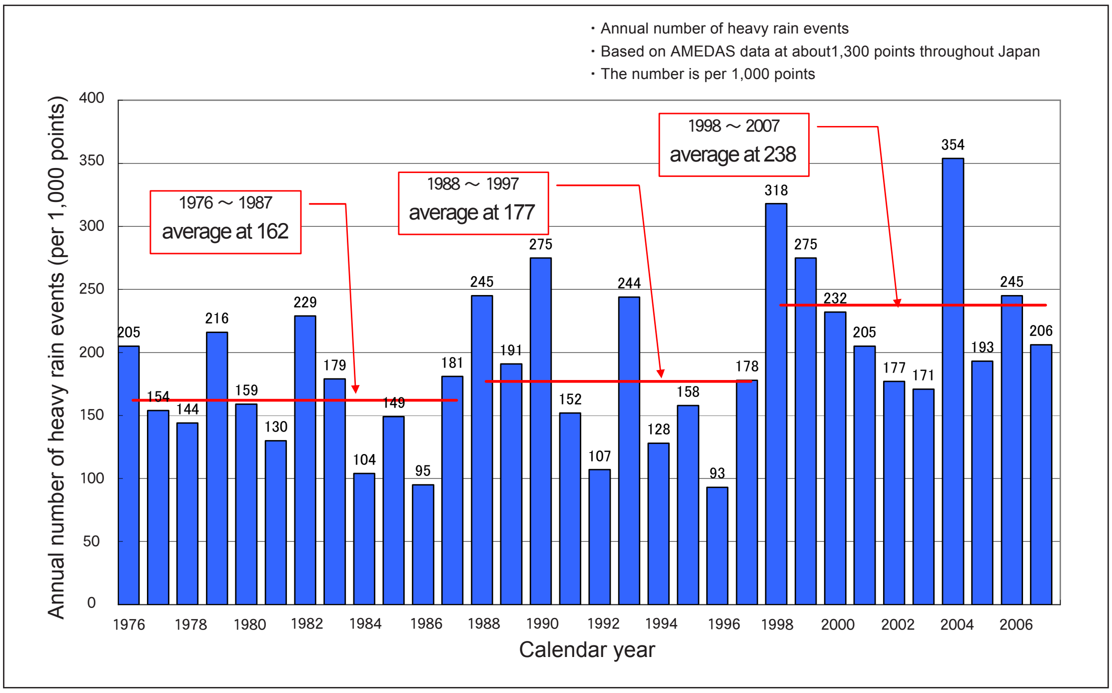


Figure 1 : Number of Heavy Rain Events with Hourly Precipitation of 50 mm or More (per 1,000 points)

Source: Reference[4]

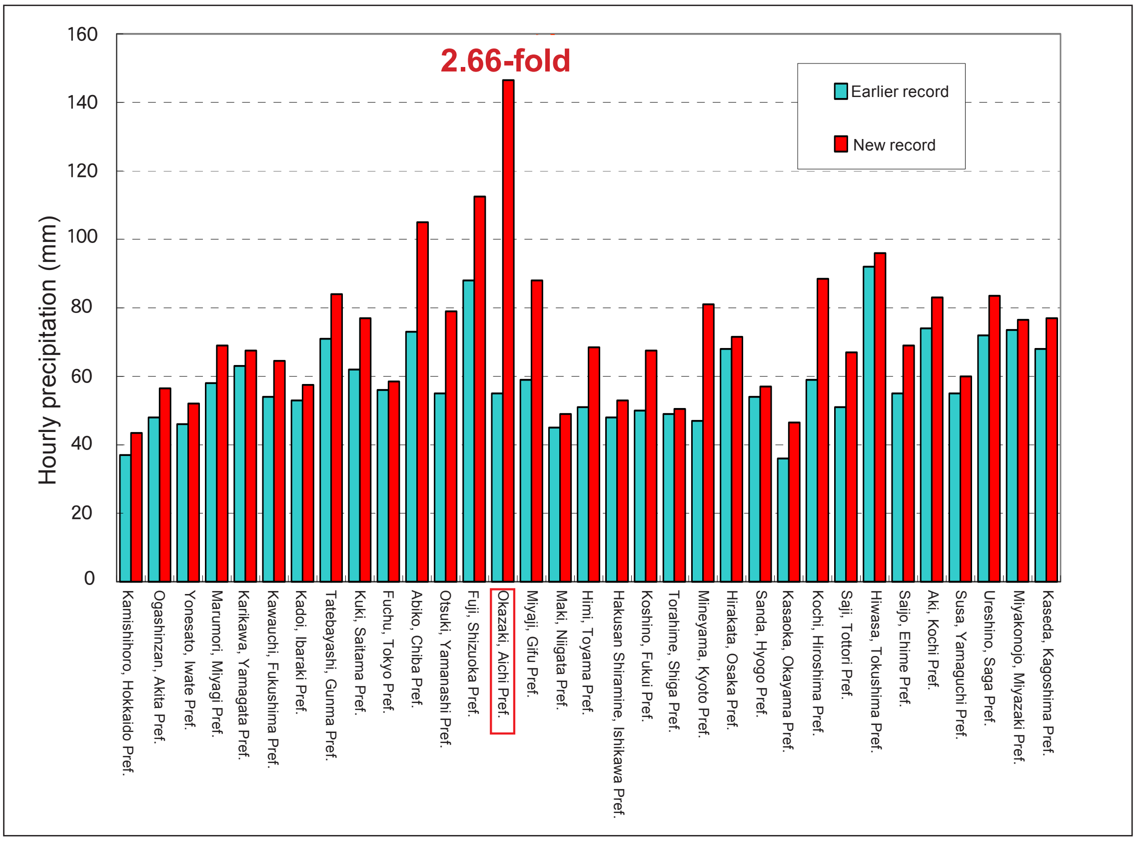


Figure 2 : Meteorological Observation Points Rewriting Maximum Hourly Precipitation Records (from January 1 to August 31, 2008)

Source: Reference[4]

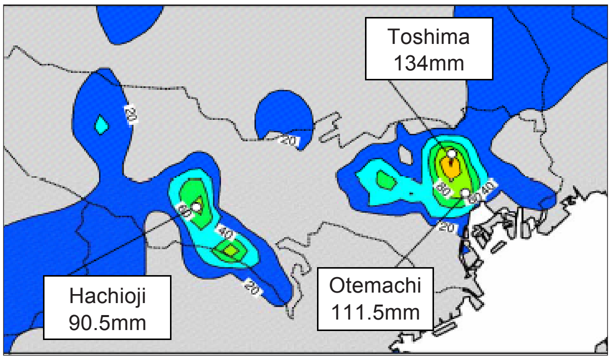


Figure 3 : Precipitation Map for Tokyo on August 5, 2008

Source: Reference[6]

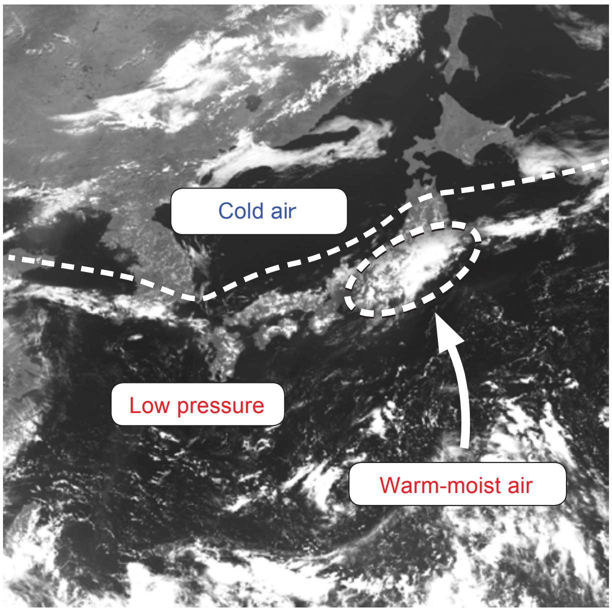


Figure 4 : Weather Camera Picture at noon on August 5, 2008

Source: Reference[6]

Table 1 : Damage Brought by Localized Heavy Rains in 2008

Date	Human Damage				House damage					Landslide
	Deaths	Missing	Injured		Demolished	Half destroyed	Partially destroyed	Inundation above floor level	Inundation below floor level	
			Heavily	Lightly						
July 28	6		1	12	6	16	61	536	2464	
August 5	5							54	153	
August 31	3			3	5	1	18	1678	8071	178

Prepared by the STFC based Reference[9]

rains in 2008. On July 28, extra-heavy rains occurred on the Toga River basin, boosting the river's water level by 1.34 meters in only 10 minutes. Five people, including infants, were washed away and killed then. Rains from cumulonimbus clouds rapidly grow heavier, boosting water levels quickly for urban fast-flowing rivers as well as shorter rivers with narrower basins to cause heavy losses.

3 Cumulonimbus Clouds Bringing Heavy Rains

3-1 *Development of Cumulonimbus Clouds*

Figure 5 indicates a conceptual diagram of the development of a cumulonimbus cloud bringing heavy rains.

The darker-shaded area of the cloud (cumulonimbus cloud) in Figure 6 represents the precipitation cell that brings heavy rains. Precipitation does not occur even if upward air currents cause rain particles during the cloud-development phase. In the maturity phase, rain particles grow larger and begin to precipitate. Then, the resistance force drives down surrounding air to cause downward currents. The cumulonimbus cloud then enters an occlusion phase with the precipitation cell disappearing. The cumulonimbus clouds feature a very short time between the start of its formation and precipitation.

3-2 *Multi-cell Type*

A cumulonimbus cloud with multiple precipitation cells is described as a multi-cell type. Multi-cell cumulonimbus clouds include "organized multi-cell" clouds in which multiple cells line up regularly and repeat their development, maturity and occlusion in an orderly manner over several hours. Organized multi-cell cumulonimbus clouds include the back-building type that features precipitation cells formed at the cloud tail, one after another. This is the type of cumulonimbus cloud seen frequently for localized heavy rains in Japan.

3-3 *Super-cell Type*

Cumulonimbus clouds that spin and are sustained for a long period of time are called super-cell. Super-cell cumulonimbus clouds cause severe weather phenomena including tornadoes, windblasts and hailstones. A super-cell cumulonimbus cloud, though with a single cell, is as large as a multi-cell cloud.

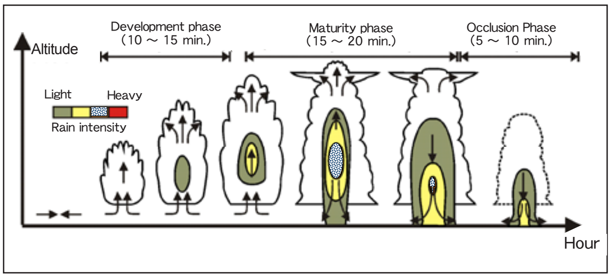


Figure 5 : Conceptual Diagram of Cumulonimbus Cloud's Life

Reference[7] as modified partially by the STFC

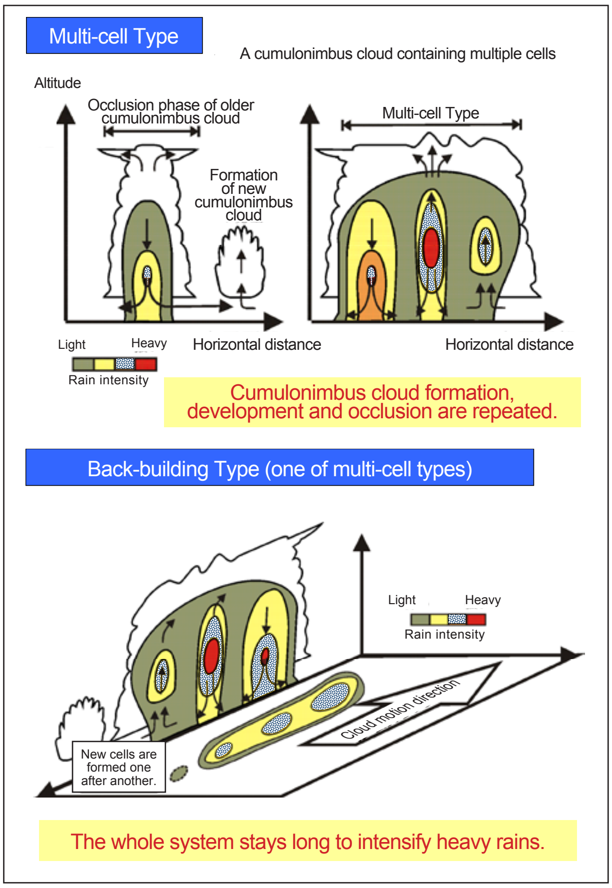


Figure 6 : Classification of Cumulonimbus Clouds (of the multi-cell type)

Reference[7] as modified partially by the STFC

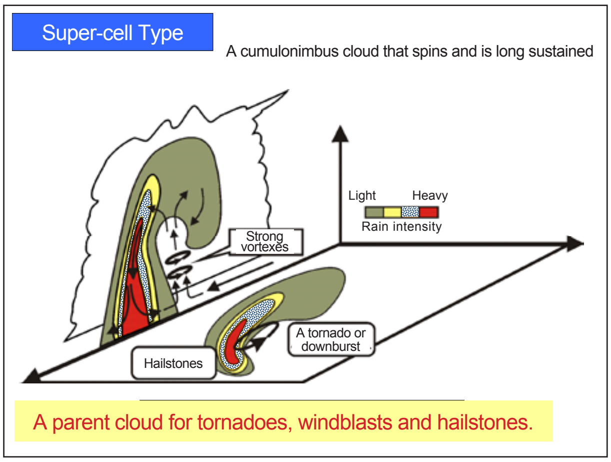


Figure 7 : Classification of Cumulonimbus Clouds (super-cell type)

Reference[7] as modified partially by the STFC

4 Rain Observation

Research into the mechanism for localized heavy rains has made progress as explained above. But any imminent localized heavy rains are still considerably difficult to forecast. The realities of the phenomenon must be grasped more precisely. Observation must be conducted to precisely grasp localized heavy rains, and peripheral or relevant phenomena. Technologies for such observation are under development.

4-1 Radar Rain Observation

The most effective means for observing rains is the radar. The radar stands for radio detection and ranging and indicates a device to detect some targets and measure distances with radio waves. Generally, a radar system for rain observation uses a spinning antenna to transmit directional pulse radio waves and receive these radio waves (radar echoes), returning after hitting rain particles and scattering. The time between the radio wave transmission and reception is used for measuring the distance and the received power for estimating the intensity of rains. Radio waves may weaken through scattering and absorption through rains. This is called radio wave attenuation through rains. Degrees of radio wave attenuation differ depending on radio wave frequencies. Higher radio wave frequencies may lead to greater attenuation. Strengths of radio waves returning after hitting targets are proportionate to the sextuple of a rain particle diameter per unit volume. This is called a radar reflection factor (unit: mm6/m3).

A wide range of frequencies from several megahertz to 100 gigahertz are used for radio waves transmitted from radar systems. While the basic principles of radio wave propagation and radar performances remain unchanged at any frequency, the radar configurations and observation targets widely differ depending on frequencies. Basically, longer wavelengths or lower frequencies are suitable for far distant large observation targets, while shorter wavelengths or higher frequencies are useful for detecting very small targets within short ranges[11]. Table 2 indicates the range of radio wave frequencies used for meteorological radars for rain observations and their features.

(1) 2.8 GHz-band Radar (S-band Radar)

This frequency band features less radio wave attenuation through rains and longer observation distances. This band has been heavily used in lower-latitude (tropical) regions, where locations for radars are limited due to heavy precipitation and dominant sea waters.[11] In the past, Japan had used this band for the Mt. Fuji radar to observe offshore typhoons within a radius of up to 800 km. As meteorological satellites are used for wide-range typhoon observation at present, however, this band is no longer used for weather observation.

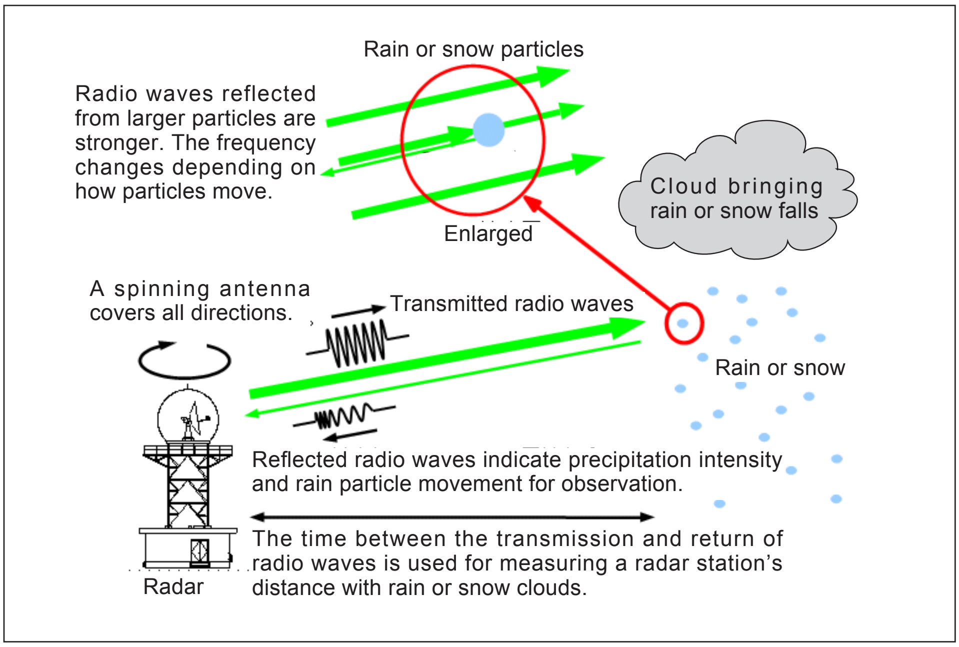


Figure 8 : Overview of Weather Radar Observation

Source: Reference[10]

Table 2 : Radio Wave Frequency Bands for Weather Radars

Representative frequency	Representative wavelength	Frequency band	Maximum observation range	Band	Features
2.8GHz	10.7cm	2.7 ～ 3.0GHz	About 200 km or more	S	Radio wave attenuation through rains is limited. Radars in this band are used for wide-area precipitation observations. The maximum observation radius is 800 km.
5.3GHz	5.7cm	5.25 ～ 5.35GHz	About 200 km	C	Radars in these bands are used for precipitation observations. These bands feature the second smallest radio wave attenuation through rains after the 2.8 GHz band.
5.6GHz	5.4cm	5.60 ～ 5.65GHz	About 200 km		
9.5GHz	3.2cm	9.3 ～ 9.7GHz	About 60 km	X	Radars in this band are used for rain and snow observations. They are not suitable for wide-area observations since radio wave attenuation is conspicuous through heavy rains. A radar system for this band is relatively smaller and cheaper.
13.8GHz	2.2cm	13.8GHz	Satellite-mounted	Ku	
35GHz	0.86cm	34.5 ～ 35.5GHz	About 30 km	Ka	Radars in these bands are not suitable for precipitation observations since radio wave attenuation through heavy rains is greater.
95GHz	0.32cm	94.5 ～ 95.5GHz	About 10 km	W	

Prepared by the STFC based Reference[11]

(2) 5.3 GHz-band Radar (C-band Radar)

This frequency band features the second smallest radio wave attenuation through rains after the 2.8 GHz band and has heavily been used in middle-latitude countries and Europe.[11] In Japan, the frequency band has been used for weather radars of the JMA and radar rain gauges of the River and Road Bureaus at the Ministry of Land, Infrastructure, Transport and Tourism.

The JMA has established 20 radars to monitor rains throughout Japan. They include nine standard weather radars using echo strengths for observing rains and 11 radars that have Doppler functions. In fiscal 2008, the JMA launched a project to develop five standard radars into Doppler systems. A Doppler radar uses the Doppler effect of radio waves to measure the velocity of precipitation particles to grasp a fine three-dimensional wind distribution within each precipitation area. Data collected through the radars are used for tornado advisories and numerical weather prediction models. The maximum observation radius is 400 km, the observation interval is 10 minutes and the planar resolution is a 1-km mesh. Radar rain observation data are corrected with ground rain gauge data. The JMA plans to halve the observation interval to five minutes.

The MLIT has established 26 radar rain gauges for river and road management throughout Japan. The maximum observation radius ranges from 200 km to 300 km. Within a 120-km radius, the radar rain gauge can perform quantitative rain observation. The radar covers a precipitation intensity range of 1 mm/h to 250 mm/h. Radar rain observation data are corrected with ground rain gauge data. The observation interval is five minutes and the planar resolution is a 1-km mesh.[12]

Data from radar rain gauges are made available along with MLIT-held disaster-prevention information on the website of the MLIT Information Service Center for Disaster Prevention[13] (managed by the JMA). Data from weather radars are published along with other weather information through the JMA website. Observation data from MLIT radar rain gauges and JMA weather radars are used as “analyzed precipitation data”[14] for very short-range and “Nowcast” precipitation forecasts.

(3) 9.5 GHz-band Radar (X-band Radar)

Radars in this band feature conspicuous radio wave attenuation in the event of heavy rains and are not suitable for wide-area rain observation. As these radars are relatively smaller, however, they are widely used as marine radars for ships. Radars in this band can also be made at lower costs than those in other bands and have been used frequently for research purposes as well.[11] Some urban local governments – Tokyo Prefecture, Saitama Prefecture, Yokohama City, Kawasaki City, Osaka City and Kobe City – have also used radars in this band for rain observation to secure accurate control of sewerage facilities and early disaster-prevention measures in heavy rain events. Particularly, these urban local governments want fine-tuned precipitation data to address urban floods. These data are published through these governments’ websites as disaster-prevention information for local residents.

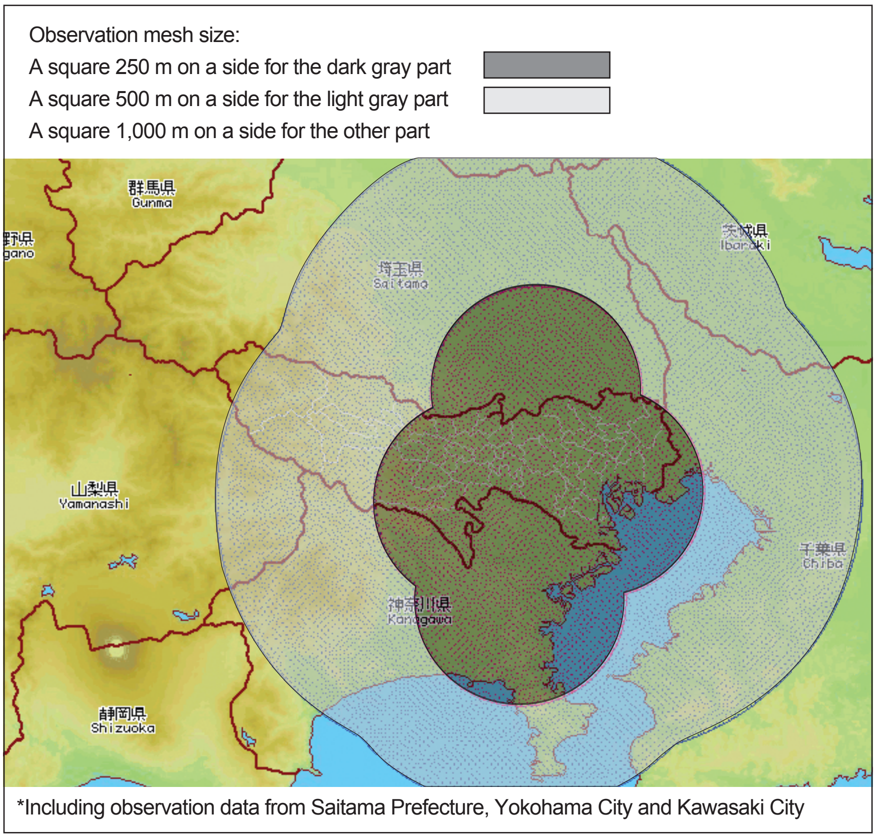


Figure 9 : Tokyo Amesh Observation Mesh Size

Source: Reference[15]

Next, I would like to introduce the Tokyo Metropolitan Government's Tokyo Amesh radar system as an example.[15] The metropolitan government's Bureau of Sewerage introduced the system in fiscal 1988 to control sewage facilities, including pumping stations and water reclamation centers. The existing system was updated in fiscal 2001, consisting of two radar stations, 86 ground rain gauges for correction of radar observation data, and terminal stations. Since fiscal 2007, the Tokyo Metropolitan, Saitama Prefecture, Yokohama Municipal and Kawasaki Municipal governments have opened their rain observation data to each other to improve observation coverage and accuracy. As indicated by Figure 9, the observation meshes include a 250-m mesh and a 500-m mesh covering fine-tuned precipitation data. These data are published through the website of the metropolitan government's Bureau of Sewerage.

(4) 35/95 GHz-band Radars (Ka-band and W-band Radars)

Radars in these bands feature even greater attenuation of radio waves through rains and are not suitable for rain observation. But they are useful for observing clouds and fogs with smaller particle sizes[11].

Since heavy rains from cumulonimbus clouds come soon after cloud formation starts, as explained in Chapter 3, Ka/W-band radars that can detect clouds are useful for monitoring heavy rains. But these radars' observation radius is limited to only 30 km. The problem is that many radar stations would have to be constructed for actual observation. The National Research Institute for Earth Science and Disaster Prevention completed a radar system of this kind in 2000 for research into the formation of cumulonimbus and other clouds and into artificial snowfalls.[16]

4-2 New Radar Observation Methods

Weather radars and radar rain gauges in the 5.3 GHz band and local governments' radars for controlling sewage facilities in the 9.5 GHz band adopt the same precipitation-observation method to estimate the rain intensity with amplitude information (reflectivity factors) of radio waves reflected from rain particles. Under the method, 10 to 15 minutes are required to establish the correlation between radar and ground rain gauge data to secure data accuracy. Since rains brought by cumulonimbus clouds can grow heavier in

10 to 15 minutes, the rain detection time may have to be shortened. As a solution, a multi-parameter radar is under research and development.

A conventional weather radar transmits radio waves in a single band and observes amplitude data of waves reflected from rain particles to estimate the rain intensity. The multi-parameter radar measures gaps between amplitude data of radio waves in two bands reflected from rain particles and their phase information, in order to acquire several types of parameters altogether. The multi-parameter radar adopts the horizontal and vertical polarized waves, the transmission of 45-degree linearly polarized waves and the simultaneous reception of horizontal and vertical polarized waves, or two types of radio waves with different wavelengths.

As an example, I would like to introduce a multi-parameter radar that the National Research Institute for Earth Science and Disaster Prevention developed in 2000. The radar features a double-polarized wave transmitter using horizontal and vertical polarized waves[16]. As indicated by Figure 10, rain particles grow larger as rains become heavier. The particles also grow flatter in shape due to a greater air resistance upon their falling. Changes in shape cause a radar-reflectivity factor and phase differences as horizontal and vertical polarized waves have different scattering characteristics. Reflectivity factors differences may be used for obtaining the Z_{DR} reflectivity difference and phase differences for calculating the K_{DP} phase difference between polarized waves. As a result, detailed data about rain particle sizes are made available for estimating the rain intensity more accurately. The Z_{DR} reflectivity factor difference is obtained from a gap between strengths of horizontal and vertical polarized waves and can be affected by the attenuation of waves through rains. But the K_{DP} phase difference between polarized waves, which is obtained from phase differences, may remain unaffected by such radio wave attenuation.

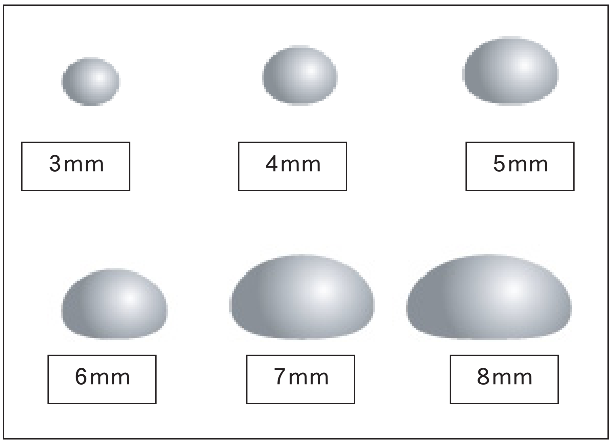


Figure 10 : Changes in Rain Particle Shape

Source: Reference[16]

Figure 11 compares rain intensities obtained from conventional radar reflectivity factors (Z_H) (R-Z_H relationship) and those from multi-parameter radar K_{DP} data (R-K_{DP} relationship) with intensities indicated by ground rain gauges. Under the R-Z_H relationship, the radar reflectivity factor is multiplied by the constant number of rain particle size distribution as obtained from many rain cases to estimate rain intensities. Therefore, the estimates can easily be affected by fluctuations in the rain particle size distribution, resulting in large estimation errors. In contrast, the R-K_{DP} relation, which uses the K_{DP} phase difference

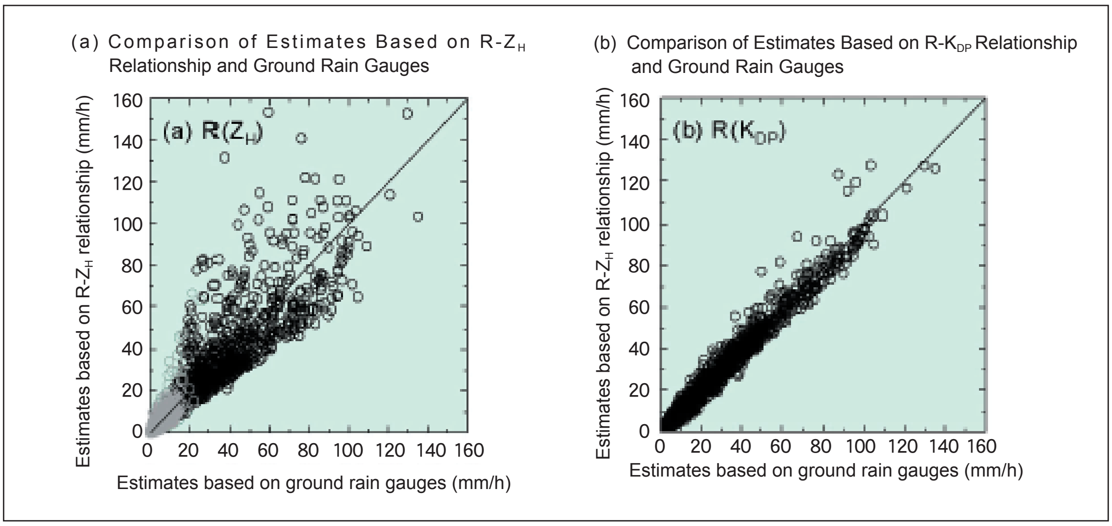


Figure 11 : Comparison of Rain Intensity Estimates Based on Radars and Ground Rain Gauges

Source: Reference[16]

between comparative polarized waves to directly obtain rain particle data from the phase difference, is little affected by the rain particle size distribution.

Graph (a) compares rain intensity estimates obtained under the R-Z_H relationship on the longitudinal axis and those from ground rain gauges on the horizontal axis. The wide data spread indicates that rain intensity estimates under the R-Z_H relationship is affected largely by fluctuations in the rain particle size distribution. Graph (b) compares rain intensity estimates obtained under the R-K_{DP} relationship on the longitudinal axis and those from ground rain gauges on the horizontal axis. The data spread in Graph (b) is narrower than in Graph (a), indicating that the estimates under the R-K_{DP} relationship are less affected by fluctuations in the rain particle size distribution. Graph (b) also shows a close correlation between rain intensity estimates from radars and ground rain gauges. The multi-parameter radar directly handles rain intensity estimates based on radar observation parameters and can detect and address localized heavy rains more promptly and precisely.

The National Research Institute for Earth Science and Disaster Prevention has adopted the X band for its multi-parameter radar. Conventional X-band radars are not suitable for observing heavy rains because radio waves in this band attenuate through rains. But this X-band multi-parameter radar can be used even amid heavy rains. The radar's observation radius is up to 80 km. The planar resolution is a 500-m mesh. The observation interval is five minutes.

Meanwhile, C-band weather radars and radar rain gauges may be combined with double-polarized wave transmitters to effectively observe rapidly developing rainstorms. The National Institute of Information and Communications Technology developed a C-band polarized-wave radar, named NICT Okinawa Bistatic Polarimetric Radar (COBRA), in 2002 and has continued observation and research with the radar[17]. Three radar rain gauges in the Kyushu Region have been modified one after another into double-polarized wave radars since 1994 for Z_{DR} method observations. Technological advancement through the development of double-polarized wave radars by the National Research Institute for Earth Science and Disaster Prevention and the National Institute of Information and Communications Technology has contributed to increasing data and improving observation accuracy. The first double-polarized radar was updated with the K_{DP} method added to the Z_{DR} method in fiscal 2008 for test operations from fiscal 2009, before full-fledged operations were planned to start in fiscal 2011.

Conventional weather radars mechanically rotate parabola antennas to gradually change radio wave transmission angles for sterical observation, consuming five to 10 minutes for observation. High temporal resolution radars must be developed to observe localized surprise atmospheric phenomena. A phased-array system for electronic beam scanning will be effective for solving the time-consumption problem. The system uses a fixed antenna to promptly change beaming directions, reducing time consumption for observation. In five years from fiscal 2008 under an industry-academia-government project, the National Institute of Information and Communications Technology plans to develop a phased-array radar to observe an area within a radius of 30 km with a space resolution of 100 m or less within 10 seconds.[18]

In addition to the C-band radar rain gauge system, the MLIT plans to develop X-band multi-parameter radar systems in Japan's three major metropolitan regions, where localized heavy rains or intense rainstorms could bring about great disasters. It intends to use these systems to enhance its surveillance on heavy rains and better control rivers from 2010.[19, 20]

5 Precipitation Forecast

The JMA provides short-term precipitation forecasts under the names of the "Very Short-range Forecast of Precipitation" and the "Precipitation Nowcasts." The Very Short-range Forecast provides forecasts of hourly precipitation amounts for the next six hours with a spatial resolution of 1 km by combining precipitation area movement speeds obtained from analyzed precipitation data with forecast precipitation amounts based on numerical predictions, as well as geographic data affecting development and occlusion of nimbus clouds.

The Precipitation Nowcasts, as a prompter information service, provide 10-minute precipitation forecasts for the next one hour every 10 minutes and are used for monitoring precipitation from cumulonimbus clouds that develop in 10 to 15 minutes. The effects of geographical landscapes, and cloud formation and development are skipped to allow

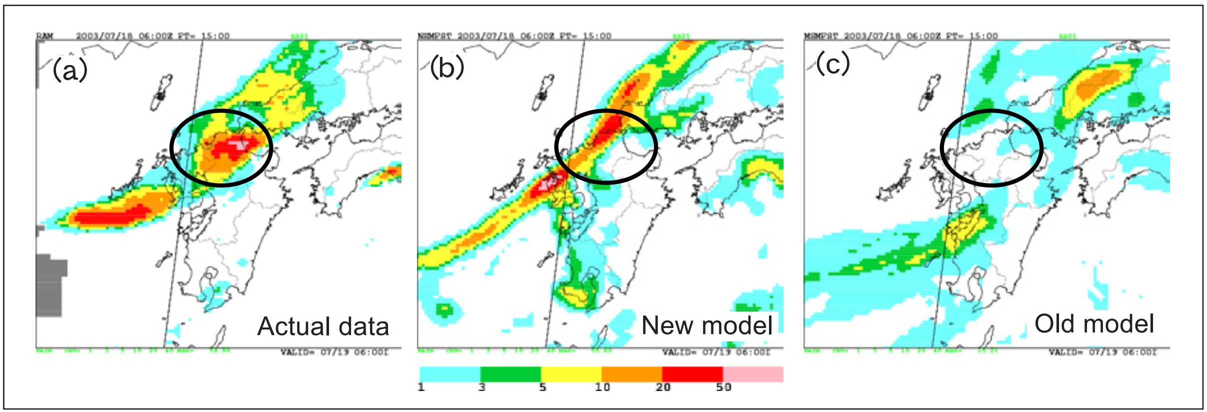


Figure 12 : Comparison of New and Old Numerical Prediction Models and Actual Data

Reference[22] as modified partially by the STFC

data to be published within five minutes from their observation.[21]

Both the Very Short-range Forecast of Precipitation and the Precipitation Nowcasts provide short-term forecasts based on present precipitation data. Although the JMA may ideally be required to predict precipitation events before such events come, the mechanism for the formation and development of cumulonimbus clouds and precipitation has yet to be clarified completely. Numerical prediction technology, which physically forecasts meteorological changes, can provide forecasts of precipitation for prefectural and other wide areas. But it is difficult at present to give precipitation predictions in a pinpointed manner. The JMA Meteorological Research Institute has been trying to clarify mechanisms for rainstorms, heavy snowfalls, typhoons and other meso-scale weather phenomena and develop technology for their predictions.

As an example of recent improvements in weather forecast technology, I would like to cite the replacement of a supercomputer in March 2006 to improve computation capacity and reduce the lattice spacing of the numerical prediction model from 10 km to 5 km. Around 5 a.m. on July 19, 2003, heavy rains with precipitation exceeding 100 mm per hour were observed in Dazaifu, Fukuoka Prefecture. Figure 12 compares the new and old numerical prediction models and actual data. Figure (a) is an actual precipitation map (based on analyzed radar AMEDAS precipitation data) for one hour before 6 a.m. on July 19. Figure (b) is a forecast precipitation map for 6 a.m. on July 19, given 15 hours ago at 3 p.m. on July 18, under the new model with the lattice spacing at 5 km. Figure (c) is a forecast precipitation map for the same time under the old model with the lattice spacing at 10 km. The new model with the lattice spacing at 5 km could predict heavy rains that the old model with the spacing at 10 km could not forecast, indicating the improved accuracy of the prediction. The forecast under the new model is closer to the actual situation. The advancement of weather forecast technology included not only the improvement of the horizontal resolution from 10 km to 5 km for the new model but also the enhancement of the precision of data for vertical air movements and the precipitation process.[22]

The advancement of the numerical prediction model can improve the precision of forecasts. The numerical prediction model is a program that divides the atmosphere into lattices three-dimensionally and gives each lattice point atmospheric condition data, including pressure, temperature and moisture content, for computation for the numerical prediction of future atmospheric conditions. In order to develop a more reproducible numeral prediction model, actual phenomena will have to be reflected in the numerical prediction model more accurately. To this end, the precipitation mechanism will have to be clarified.

In a bid to advance numerical prediction models, the JMA Meteorological Research Institute has been trying to clarify the precipitation mechanism by using numerical models for reproduction computation and conducting numerical analyses of more reproducible models. When the latest data including air pressure, temperature, wind and moisture content are given to each lattice point for numerical predictions, the latest predicted data, and spatially and temporally uneven observation data are used with considerations given to their error margins to obtain optimum analytical data that are physically consistent as lattice point data. The technology to secure the consistency of predicted and observed data and incorporate consistent data into numerical prediction models is called "data assimilation." Since the accuracy of predictions given by numerical prediction models depend on the accuracy of data for initiating predictions, research efforts to improve the data assimilation technology are also important.

Numerical prediction models can indicate a meteorological phenomenon that is more than five times as large as the lattice spacing. Smaller lattice spacing may allow more phenomena to be indicated. Unless physical processes of meteorological phenomena are made suitable for lattice spacing, however, smaller lattice spacing alone may not necessarily improve the accuracy of predictions. A smaller lattice spacing may bring about a greater number of lattice points to increase data for computation. The lattice spacing for JMA-used numerical prediction models is now at 5 km. Cumulonimbus cloud sizes range from a few km to 10 km and may fail to be fully covered by a 5 km lattice. Given its supercomputer replacement planned for 2011, the JMA plans to initiate localized numerical prediction models with the lattice spacing reduced to 2 km by 2012.[23] The advancement of observation equipment and numerical prediction models is increasing the possibility of localized heavy rains being predicted.

6 Conclusion

Global warming is feared to bring about an increase in the frequency of heavy rain events. The Cabinet Office and other administrative organizations and research institutes responsible for rain disaster prevention are required to advance precipitation-observation technology and enhance disaster-prevention measures.

In nature, meteorological phenomena can be explained by laws of physics. Using the laws are numerical predictions as the core of weather forecasts. As actual meteorological phenomena are affected by many factors, however, localized heavy rains as a minor part of large atmospheric phenomena have failed to be reproduced by numerical predictions. In order to address the situation, Japan should develop more precise observation equipment, conduct fine-tuned observation, accumulate observed data and promote research and development of technology for precise indication of physical law based on these data.

Acknowledgement

In writing this report, I received precious comments, advices and data from Mr. Hiroshi Yokoyama, Senior Coordinator for Research and Development, Planning Division, Administration Department, Japan Meteorological Agency; Mr. Susumu Goto, Senior Policy Coordinator, Planning Division, Administration Department, Japan Meteorological Agency; Mr. Harunori Gohda, Deputy Director, Forecast Division, Forecast Department, Japan Meteorological Agency; Mr. Takuya Hosomi, Chief Official, Administration Division, Forecast Department, Japan Meteorological Agency; Mr. Hakaru Mizuno, Observations Division, Observations Department, Japan Meteorological Agency; Mr. Masahito Ishihara, Director-General, Satellite and Observation System Research Department, Meteorological Research Institution, Japan Meteorological Agency; Mr. Masaomi Nakamura, Head of the 1st Laboratory, Forecast Research Department, Meteorological Research Institution, Japan Meteorological Agency; Mr. Takahito Nishinomiya, Deputy Director, Planning Office, Forecast Research Department, Meteorological Research Institution, Japan Meteorological Agency; Mr. Ryohei Misumi, Senior Researcher, Storm, Flood, and Landslide Research Department, National Research for Earth Science and Disaster Prevention; and Mr. Sninsuke Sato, Senior Researcher, Environment Sensing and Network Group, Applied Electromagnetic Research Center, National Institute of Information and Communications Technology. I also received precious data and information from Mr. Kazuhiro Unoki, Deputy Director, River Management Division, Kyushu Regional Development Bureau, Ministry of Land, Infrastructure, and Transport and Mr. Hidero Ohashi, Chief of Facilities Management Division, Facilities Management Department, Bureau of Sewerage Tokyo Metropolitan Government. I am deeply grateful to all of these persons.

References

[1] Summary for Policy Makers, Integrated Report, IPCC Fourth Assessment Report 2007, MEXT, METI, JMA, and MOE：http://www.env.go.jp/earth/ipcc/4th/interim-j.pdf

[2] Announcement of Envisioned Water Immersion Damages to Subways etc. when the Arakawa River Embankment Collapses, Cabinet Office Press Release on Jan. 23, 2009：http://www.bousai.go.jp/jishin/chubou/suigai/090123/090123_kisya.pdf

[3] Basics of Global Warming 2008, Meteorological Research Institution, Japan Meteorological Agency：http://www.mri-jma.go.jp/Dep/cl/cl4/ondanka/text/ondan.pdf

[4] 2007 Climate Change Monitoring Report, March 2008, Japan Meteorological Agency：http://www.data.kishou.go.jp/climate/cpdinfo/monitor/2007/pdf/CCMR2007_all.pdf

[5] First WG Presentation Material on Measures against Local heavy Rain on Small and Medium Sized Rivers, Sep. 24, 2008, Ministry of Land, Infrastructure, Transport and Tourism

[6] Tokyo Weather News Flash regarding the Heavy Rain on Aug. 5, 2008 by Tokyo District Meteorological Observatory, Aug. 6, 2008

[7] Data by National Institute of Information and Communications Technology

[8] Atmospheric Flows that Caused the ‘Torrential Rain at the End of August 2008’, Press Release by Japan Meteorological Agency on Sep. 12, 2008

[9] Detailed Report on Disaster Information, Fire and Disaster Management Agency

[10] Outline of Observation by Weather Radars, Japan Meteorological Agency Website：http://www.jma.go.jp/jma/kishou/know/radar/kaisetsu.html

[11] “Remote Sensing of Atmospheric Current and Flow” by Shoichiro Fukao and Kyosuke Hamazu, 2005, Kyoto University Press

[12] Radar rain gauge course for practical engineers, Foundation of River & Basin Integrated Communications, Japan：http://www.river.or.jp/reda/index.html

[13] Ministry of Land, Infrastructure, Transport and Tourism, Disaster Prevention Information Center：http://www.bosaijoho.go.jp/

[14] Precipitation analysis, Japan Meteorological Agency Website：http://www.jma.go.jp/jma/kishou/know/kurashi/kaiseki.html

[15] Tokyo Amesh, Tokyo Metropolitan Government Website：http://tokyo-ame.jwa.or.jp/

[16] Rainfall observations by the X band multi-parameter radar, National Research Institute for Earth Science and Disaster Prevention Website：http://www.bosai.go.jp/kiban/radar/pdf_file.htm

[17] Katsuhiro Nakagawa, Hiroshi Hanato, Shinsuke Sato, Toshio Iguchi, Development of CRL Okinawa Bistatic Palarimetric Rader (COBRA), Vol.48, No.2, June, 2002, Review of the Communications Research Laboratory：http://www.nict.go.jp/publication/shuppan/kihou-journal/kihouvol48-2.htm

[18] “Research and development on Doppler radar technology for the next generation” by National Institute of Information and Communication Technology：http://www2.nict.go.jp/q/q265/s802/info/20080523koubo/theme_b003_koubo.pdf

[19] Third WG Presentation Material on Measures against Local heavy Rain on Small and Medium Sized Rivers, December 1, 2008, Ministry of Land, Infrastructure, Transport and Tourism

[20] “Don’t miss torrential rains”, January 7, 2009, the Asahi Shimbun Company

[21] Meteorological guidebook 2007, March 31, 2007, Japan Meteorological Agency

[22] “Introduction of the New Numerical Weather Prediction Model use for Disaster Prevention and Weather Information”, Press Release by Japan Meteorological Agency on July 22, 2004：http://www.jma.go.jp/jma/press/0407/22a Japan Meteorological Agency /suchimodel.pdf

[23] “Predict torrential rains, Development of Weather Prediction Model by Japan Meteorological Agency after an interval of twelve years”, August 15, 2008, Asahi.com：http://www.asahi.com/eco/TKY200808150217.html

Profile

Eiichi SHIRAISHI
Senior Fellow, Monozukuri, Infrastructure and Frontier Research Unit, STFC
http://www.nistep.go.jp/index-j.html

Engaged in river surveys, planning and management at the Ministry of Land, Infrastructure, Transport and Tourism. In charge of social infrastructure at the STFC.

(Original Japanese version: published in February 2009)

7

Current Status and Future Issues of Volcanic Eruption Prediction Research

Eisuke Fujita
Affiliated Fellow

1 Introduction

Japan is located in an area where the Pacific plate and the Philippine plate subduct below the Eurasian plate. As part of the Pacific Ring of Fire, Japan is one of the most noted volcanic countries in the world. Japan has 108 active volcanoes, which are defined by international standards as volcanoes that have erupted approximately within the past 10,000 years or those that are currently in active fumarolic activity (Figure 1). During quiet times, volcanoes bring about numerous blessings by allowing agricultural produce to grow and providing tourism resources such as hot springs, thus providing a livelihood for nearby residents. However, once an eruption occurs, it can lead to enormous disasters. Volcanic disasters are complex disasters caused by various factors, in contrast with earthquake disasters, which are mainly caused by tremors (Table 1).

In Japan's recorded history, there have been at least 30 volcanic disasters involving human damage. The greatest damage came in 1792 with the eruption of the Unzen volcano, Fugen-dake, in which an avalanche triggered a tsunami that killed some 15,000 people. In recent years, 43 people were killed in 1991 by pyroclastic flows following yet another eruption of the Unzen volcano, Fugen-dake. However, recent volcanic disasters involve far less extensive human damage compared to the Edo Period and earlier. This is due to the fortunate fact that Japan's last few major eruptions occurred more than a couple hundred years ago, such as the Houei eruption of Mt. Fuji in 1707, the Tenmei eruption of Mt. Asama in 1783 and the 1792 eruption of Mt. Unzen and the subsequent collapse of Mayu-yama. Another reason is the improved abnormality detection capabilities thanks to recent volcano observation networks, and effective evacuation and other measures taken once abnormalities have been detected.

Compared to earthquake prediction, volcanic eruption predictions are relatively easier to make. Of the five elements of prediction—when, where, how large, what kind and until when—in terms of "where," volcanoes, especially in the early stages of activity, have the advantage that, in a broad sense, their spatial location is known. Since volcanic activity is associated with magma movement, the "when" element can also be known to a certain extent by capturing precursory phenomena such as volcanic earthquakes prior to the eruption. In recent years, precise observations have enabled abnormalities to

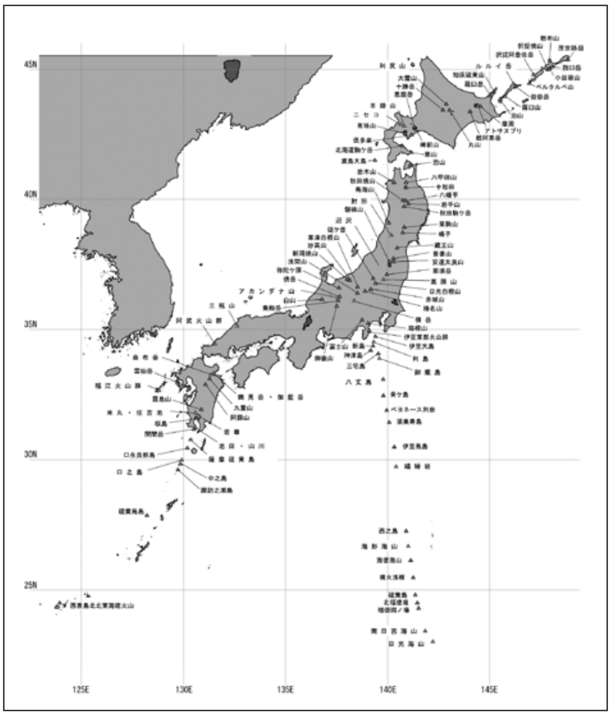


Figure 1 : Distribution map of active volcanoes in Japan

Prepared by the STFC based on Reference[1]

Table 1 : Volcanic disaster classifications

Factors that cause damage	Volcanic activity
Direct damage due to volcanic ejecta	● Ash falls and cinders ● Pyroclastic flows ● Lava flows ● Blasts ● Air vibrations ● Volcanic gas ● Volcanic mudflow (First lahar)
Damage due to terrestrial phenomena caused by volcanic activity	● Avalanche ● Crustal deformation ● Volcanic earthquakes ● Geothermal heat ● Tsunami
Indirect damage	● Mudflows and debris flows ● Slope failures ● Landslides (Second lahar)

Prepared by the STFC

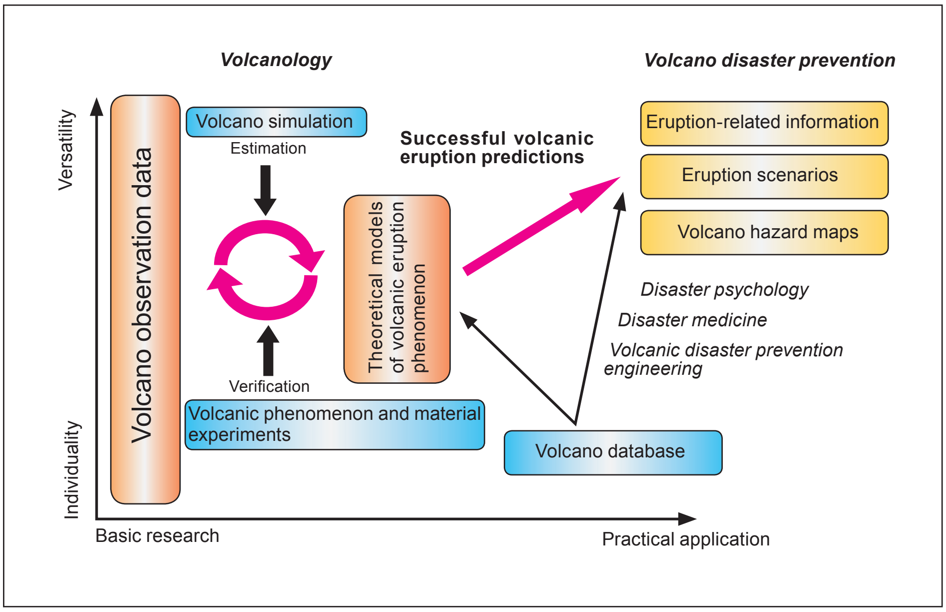


Figure 2 : Volcanology and volcano disaster prevention concepts

Prepared by the STFC

be detected and even information of an imminent eruption can be transmitted. Basically, predictions of several hours to several days in advance are possible, although they depend on magma property and vent stability. Notable examples include the 1986 eruption of Izu-Oshima, the 1989 volcanic activity in the east coast of the Izu Peninsula and the 2000 eruptions of Mt. Usu and Miyake-jima, in which prior earthquake swarms and crustal deformations were detected and this information was utilized in evacuation activities. In 1998, Mt. Iwate provided a valuable experience when fumarolic and seismic activities pointed to a possible eruption but ended in a non-eruption—or an "attempted eruption." Also, in Mt. Fuji, deep low-frequency seismic activity increased in 2000–2001 and, while it did not culminate in an eruption, the event led to the realization that an eruption of Mt. Fuji was a realistic possibility and raised awareness of the need for disaster-prevention measures.

On the other hand, however, it is difficult to obtain accurate information about "when the eruption will end." The 2000 eruption of Miyake-jima experienced phenomena that had never before been observed in the world, such as the first caldera formation in 2,500 years and prolonged volcanic gas emissions; and while prior magma activity was captured, it was difficult to predict progressions in volcanic activity. This eruption highlighted the fact that volcanic eruption predictions have depended largely on past experiences. Regarding magma activity, which is the root of volcanic activity, some knowledge has been gained about magma chambers at depths of up to 10 kilometers, but there is no information available for deeper magma chambers, particularly those at depths of around 20 kilometers or more. The lack of information about magma supply mechanisms at greater depths has made it difficult to predict volcanic activity progression.

In order to successfully predict volcanic eruptions, it is necessary to establish a theoretical model that describes volcanic-eruption phenomena accurately. A theoretical model that describes phenomena from magma ascent to eruption with greater accuracy can be established by shedding light on the eruption mechanism. This can be achieved by facilitating mutual feedback between data obtained from volcano observations, which serve as the basis of all research, and theoretical models of volcanic activity. Techniques such as experiments and simulations will be used. The use of theoretical models established in such a way would enable predictions of future volcanic eruptions and, as a result, allow practical applications to volcanic disaster prevention measures such as providing eruption information. Additionally, successful volcanic disaster prevention requires not only the advancement of volcanology, but aspects of disaster psychology, medical sociology, and volcanic disaster prevention engineering also need to be developed in a comprehensive manner.

Volcanic eruption prediction research is conducted based on feedback from an academic aspect of shedding light on the mechanisms of nature as well as an administrative aspect of contributing to volcanic disaster prevention for a safer society and life (Figure 2). In the chapters that follow, volcanic eruption prediction research will be discussed from a scientific perspective, and issues regarding volcanic disaster prevention measures that put the research findings to practical use will be addressed.

2 Developments in volcanic eruption prediction research in Japan

2-1 What is volcanic eruption prediction research?

The objective of volcanic eruption prediction research is to predict the five elements of eruption: its timing, location, magnitude, type and progression. The development of eruption prediction research can be largely divided into three stages.[2]

- **Development Stage 1**
  Abnormalities in volcanic activity can be detected from volcano observations.
- **Development Stage 2**
  The causes of the abnormalities can be estimated from volcano observations and past experiences.
- **Development Stage 3**
  Predictions can be made by applying observation results to the identified laws of physics that govern volcanic phenomena.

Looking at research on the timing of eruption, various time scales exist, ranging from eruption records covering tens of thousands of years to hundreds of thousands of years, to those covering the period immediately before the eruption. Roughly speaking, it can be divided into long-term prediction (risk assessment) and imminent prediction.

Long-term prediction (risk assessment) aims to achieve long-term stability of livelihoods and coexistence in volcanic areas through land use planning, construction of mudflow control dams, and other means. It includes assessments for the installation of nuclear facilities and geological disposal of radioactive material. For long-term prediction, it is necessary to determine the eruption history. To this end, analyses of rock materials from distribution surveys of volcanic ash and other ejecta, as well as from trench and boring surveys, are conducted. The results are put together in a staircase diagram (Figure 3) of eruption records. In staircase diagrams, the horizontal axis represents time and the vertical axis represents accumulated ejecta volume, and the interval between volcanic activities, as well as the magnitude of each volcanic activity, can be identified.

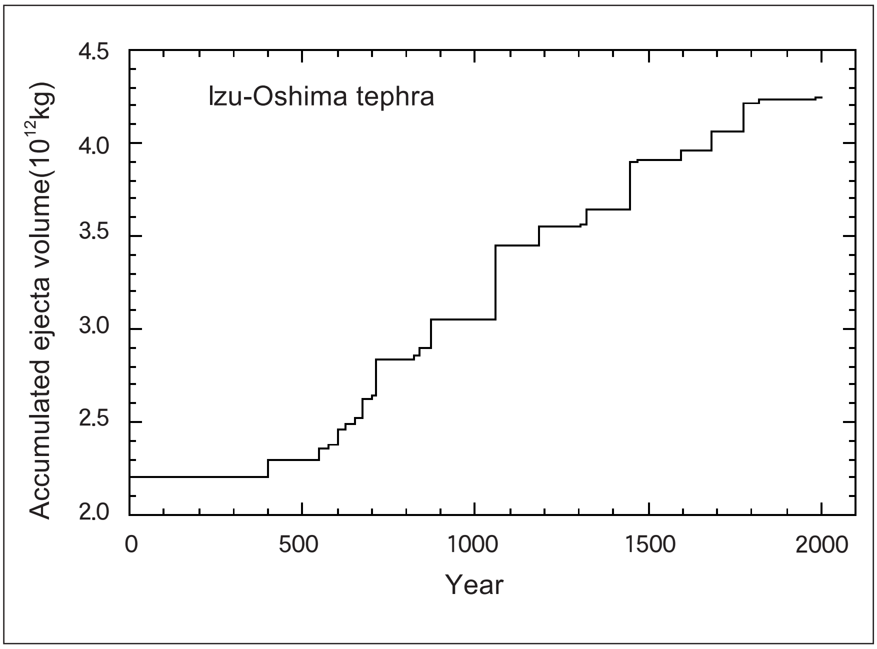


Figure 3 : Staircase diagram example showing eruption record (Volcanic ash volume ejected from Izu-Oshima volcano over the past 2,000 years)

Prepared by the STFC based on Reference[3]

In contrast, imminent prediction is based on volcano observation data. In volcano observations, data are basically accumulated from continuous physical observations of earthquakes, crustal deformation, gravity, magnetic force and electromagnetic fields, as well as chemical observations of volcanic gas, water, and more. When fluctuations different from normal times are detected in the data, the possibility of eruption is considered based on a comprehensive evaluation. However, no common or universal rule has been found, as each volcano has different magma properties and other characteristics. In reality, most judgments depend largely on empirical cases, such as past eruptions and abnormalities. The Coordinating Committee for Prediction of Volcanic Eruptions, to be described later, basically conducts short- and mid-term volcanic activity assessments and, based on various data, discusses issues related to forecasting the volcanic activity progression following an eruption.

2-2 History of volcanic eruption prediction research in Japan

The first volcano observation in Japan took place in 1888, when observations of volcanic earthquakes were made on Mt. Bandai[4]. Long-term seismic observations were conducted following a major eruption on July 25 of that year. The observation was thus aimed at grasping the activities, rather than predicting them. This was followed by temporary earthquake observations of the 1910 eruption of Mt. Usu and, in the same year, Japan's first regular earthquake observation was conducted by the Japan Meteorological Agency with respect to the eruption of Mt. Asama. Observations were made on Yake-dake in 1912 and Sakura-jima in 1914. During or prior to World War II, the installation of a full-fledged regular seismic observation network by the Japan Meteorological Agency, other than the one at Mt. Asama mentioned earlier, was limited to Mt. Aso (1931), Izu-Oshima (1939) and Miyake-jima (1943). After the war, observations took place at Mt. Usu and Mt. Azuma (1950), Mt. Tarumae and Sakura-jima (1951), Meakan-dake (1956), Tokachi-dake, Hokkaido Komagatake, Unzen-dake, Nasu-dake and Mt. Kirishima (1959). At present, there are as many as 34 constantly monitored volcanoes.

Meanwhile, volcano observations at universities began in 1933 with the establishment of the Mt. Asama volcano observatory by the University of Tokyo's Earthquake Research Institute. The observatory produced findings on classifications and frequencies of volcanic earthquakes, and led the way internationally in the early stages of volcano observation. The move was followed by Kyoto University (Mt. Aso, Sakura-jima, etc.), Kyushu University (Unzen volcano Fugen-dake, etc.), the Tokyo Institute of Technology (Mt. Kusatsu-Shirane), Tohoku University (volcanoes in northeastern Japan) and Hokkaido University (Mt.

Usu and other volcanoes in Hokkaido). Subsequently, the National Research Institute for Earth Science and Disaster Prevention (Iwo Jima, Mt. Fuji, etc.) and the Geographical Survey Institute (crustal deformation observations, etc.) have also conducted volcano observations aimed at predicting volcanic eruptions. Thus, in the history of volcano observations in Japan, the Japan Meteorological Agency's observation network has been supplemented by observation networks and the expertise of universities and research institutes, instead of a single organization conducting volcano observations.

2-3 Eruption prediction programs in Japan

In Japan, the government's guidelines for volcanic eruption prediction are prepared by the Geodesy Council's Volcano Subcommittee, and projects are implemented based on the guidelines. The guidelines were first compiled in 1973.[4] The first eruption prediction program, "Promotion of a volcanic eruption prediction program" (proposal), was submitted by the Geodesy Council's Volcano Subcommittee on June 29, 1973, and, based on this proposal, the Coordinating Committee for Prediction of Volcanic Eruptions, a private advisory panel of the Japan Meteorological Agency's director-general, was launched on June 20, 1974, with the Japan Meteorological Agency serving as the secretariat. The launch of the Coordinating Committee helped to establish a cooperative framework among relevant organizations, such as information exchange related to volcanic activity and measures to be taken in the event of a major eruption (Figure 4).

Since then, seven volcanic eruption prediction programs have been formulated and implemented, each as a five-year program. The outline of each eruption prediction program is shown in Table 2. In formulating each program, discussions have taken place in view of the current situation as well as the future direction, with the collaboration of various related organizations.

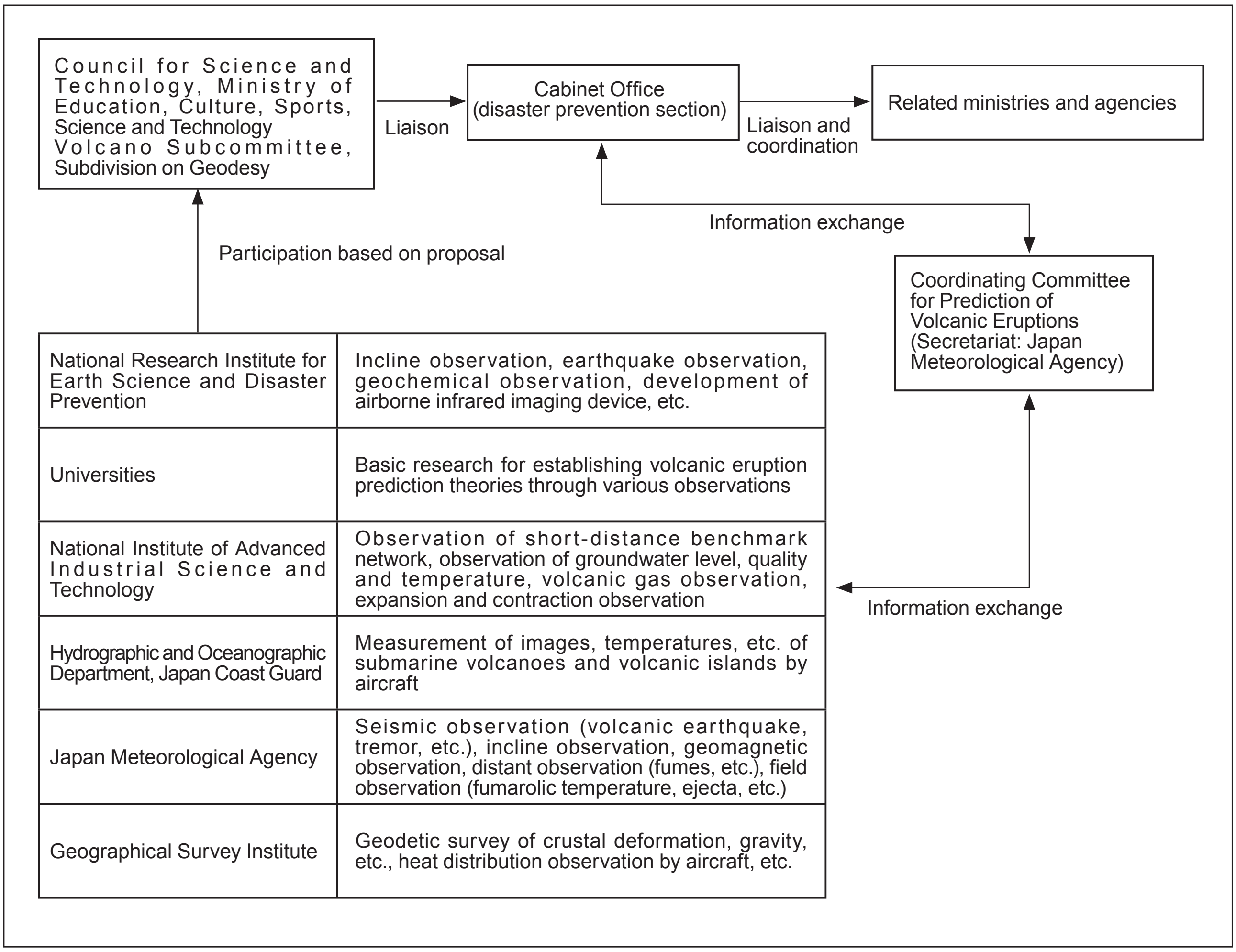


Figure 4 : Volcanic eruption prediction framework of Japan

Prepared by the STFC based on Reference[5]

Table 2 : History of volcanic eruption prediction programs

First program (1974~1978)	● Volcano observatory established on Mt. Usu. ● Annual operation of concentrated and comprehensive observation squad targeting Sakura-jima and other specified volcanoes. ● Establishment of the Coordinating Committee for Prediction of Volcanic Eruptions.
Second program (1979~1983)	● Classification of target volcanoes into "particularly active volcanoes" and "other volcanoes." ● Development of prediction methods, promotion of basic research and strengthening of volcanic eruption prediction framework.
Third program (1984~1988)	● Enhancement and strengthening of detailed observation research in view of volcanic properties. ● Promotion of prediction method development and basic research on the volcanic eruption mechanism.
Fourth program (1989~1993)	● Increased number of factors, higher density, and greater accuracy of observation. ● Promotion of the development of a system that immediately recognizes the imminent precursors of an eruption, as well as basic research to accurately grasp the dynamic process of magma.
Fifth program (1994~1998)	● Implementation of observation research for grasping the volcanic body structure, with the aim of improving the understanding of magma. ● Promotion of wide-ranging basic research related to magma activity and eruption phenomena, as well as the development of new prediction methods.
Sixth program (1999~2003)	● More effective use of volcano observation data by strengthening coordination among related agencies. ● Implementation of new observation that captures underground magma condition and movement. ● Basic research aimed at identifying the properties and behaviors of volcanic fluids involved in volcanic activity, as well as the eruption process and mechanism. ● Basic research on eruption potential assessment, such as accumulating eruption history-related data. ● Organization and consideration of active volcanoes newly subject to focused observation research.
Seventh program (2004~2008)	● Strengthening of necessary monitoring observation and provision of constant observation system, with the long-term objective of quantitatively finding the activity levels of all active volcanoes. ● Identification of magma supply system and eruption occurrence site structures, as well as understanding their changes with time. ● Building of a physicochemical model of eruption, based on a quantitative understanding of the eruption occurrence mechanism.

Prepared by the STFC based on References[4,6,7]

The first program focused on the establishment of the Coordinating Committee for Prediction of Volcanic Eruptions as a framework for volcanic eruption prediction research, and the second program focused on the classification of target volcanoes and improving and strengthening the framework. The third and fourth programs enhanced the observation framework, which enabled an understanding of the background conditions, and gradually led to the detection of abnormalities in volcanic activity and assessment of each volcano's activities. Notably, in Sakura-jima and Izu-Oshima, progress was made in understanding phenomena immediately before an eruption, and magma supply systems and their behaviors were identified. It was also shown that volcanoes such as Mt. Usu, Mt. Asama and Miyake-jima, where high-density, multiple-factor and high-accuracy monitoring observation systems were provided, were approaching the stage where accurate volcanic activity assessments and predictions of eruption occurrences were possible.

As the next step after the first four programs provided knowledge about abnormality detection, the fifth program focused on research aimed at finding out about the magma supply system, such as the subterranean structure of volcanoes and magma depth, volume and condition. Notably, in Unzen-dake and Mt. Kirishima, details of the seismic velocity structure became clear thanks to strenuous structural exploration efforts using artificial earthquakes.

The sixth program demonstrated the effectiveness of the observation networks and prediction methods that had been developed and promoted since the launch of the eruption prediction program, when Mt. Usu and Miyake-jima erupted during the project term. At the same time, however, the eruptions led to the discovery of further problems that needed to be solved, specifically, the difficulty of predicting the progression after the start of an eruption. In volcano observations based on coordination among related organizations, high-quality observation data were useful not only for basic research but also for disaster prevention measures, as grasping the volcanic activity of Miyake-jima led to the evacuation of the entire island population. In terms of promoting basic research aimed at enhancing volcanic eruption predictions, data regarding three-dimensional structures and dynamic magma activity were obtained from experimental observations at Mt. Iwate. In addition, regarding material science research on magma-degassing mechanisms, gradual progress was made in theoretical research aimed at finding out the eruption mechanism. Progress was made in strengthening the volcanic eruption prediction framework, with research facilities created at universities to continue and promote research and observations, as well as the establishment of the Volcanic Observations and Information Center within the Japan Meteorological Agency.

Regarding the current seventh program, a mid-term review of the status of implementation was compiled in January 2007[8]. According to the review, in terms of volcano observation research, real-time crustal deformation analysis was close to transpiring thanks to the Geographical Survey Institute's nationwide placement of GPS-based electronic benchmarks. In the 2004 eruption of Mt. Asama, multiple-factor observation networks that included broadband seismographs, tiltmeters, GPS, gravity and volcanic gas successfully grasped the long-term activity changes leading up to the eruption as well as precursor fluctuations immediately before eruption, thus achieving positive results toward practical eruption predictions. The review noted that the foundations of eruption-potential assessment were being established gradually, thanks to the understanding of magma supply systems due to a comprehensive interpretation of seismic velocity structure and electrical resistivity structure, systematic geological surveys, and systematic chemical analyses and dating of rocks.

It is noteworthy that, particularly in the sixth and seventh programs, advancements in remote sensing technology have brought about significant progress in volcanology as well. The establishment of the GPS-based observation network, GEONET, by the Geographical Survey Institute, and the development of Synthetic Aperture Radar (SAR) technology of satellite Daichi, have made it easy to obtain surface information on crustal deformations.[9] In addition, imaging of magma systems in the shallow parts of the volcanic body made progress following the development of cosmic-ray muon transmission radiography methods for volcanic interiors.[10]However, this was limited to imaging of the very shallow parts immediately beneath the crater, as transmission radiography is not possible if there are sediments of 1.5km or more in thickness.

2-4 Large-scale academic projects

Notably important findings have been obtained from large-scale basic research projects that are conducted in parallel with volcanic eruption prediction programs. Two examples of large-scale projects conducted in recent years are described here. While the results of these projects may not be immediately applicable to eruption predictions, finding out the eruption mechanism should contribute to volcanic eruption predictions, including eruption potential assessments.

① " Multidisciplinary Approach on Volcanic Activity of Fuji Volcano and Advancement of Related Information" (Leading research project of the Special Coordination Funds for Promoting Science and Technology, Ministry of Education, Culture, Sports, Science and Technology; FY2001–FY2004; Project leader: Toshitsugu Fujii)[11]

Following an increase in deep low-frequency seismic activity at Mt. Fuji in 2000, the project was conducted in three sub-themes with the objective of finding out the eruption history and current conditions of Mt. Fuji in preparation for possible future volcanic activity. In the "Study on low-frequency earthquakes and magma accumulation processes," high-quality observations of earthquakes, crustal deformations and ground potential found that the epicenters of low-frequency earthquakes were lined up in the northeast of the summit crater at depths of around 15km underground in the northwest-southeast direction, that a low-specific resistance zone existed at depths of around 30km, and that there was no significant crustal deformation accompanying volcanic activity. In the "Study on eruption history," Mt. Fuji's ejecta were analyzed based on surface surveys, trench surveys and drilling surveys, and there were interpretations of transitions in the magma supply system over time. These studies showed that Mt. Fuji comprised four volcanoes, instead of the commonly believed three.

The "Study on advancement of information" studied the social damage, volcanic information transmission and evacuation framework in the event of a possible massive ash fall such as the one seen in the 1707 Houei eruption of Mt. Fuji, and found an important direction in terms of the relationship between scientists and residents.

② " Dynamics of volcanic explosion" (Specified area research project of the grant-in-aid scientific research, Ministry of Education, Culture, Sports, Science and Technology; FY2002–FY2006; Project leader: Yoshiaki Ida)[12]

To predict volcanic eruptions, it is necessary to determine the explosion phenomenon mechanism. While pioneering research projects have taken place in the United States and Europe, "Dynamics of volcanic explosion," a specified area research project of the Ministry of Education, Culture, Sports, Science and Technology's grant-in-aid scientific research, was the first such project in Japan. Some 80 researchers from across Japan took part in this project. In contrast to previous volcanic eruption prediction research, which leaned toward observation and analysis techniques, the project aimed to discover more about the explosion phenomenon by coordinating observation, modeling and experimental approaches. As the first step toward a volcanic eruption, a site of occurrence is formed where magma is accumulated underground and explosive energy is maintained. This site includes rocks that surround accumulated magma and hydrothermal fluids, as well as the magma and fluids themselves. Once the site is ready for explosion, magma begins to rise and the hydrothermal fluid temperature increases, culminating in volcanic explosions such as magmatic and phreatic explosions. As a result, fumes and pyroclastic flows emerge on the surface, leading to volcanic disasters. The project comprised five research themes (site of occurrence, preparation process, mechanism, surface phenomenon and volcanic disasters) and new equipment using robotic vehicles and Doppler radars were developed to observe active volcanoes. Additionally, numerical analysis codes that incorporated properties specific to volcanic materials were developed, enabling new findings regarding the physics of multiphase magma-bubble flows. Furthermore, the elementary steps of an eruption became clear following magma foam experiments and explosion and shock wave tube experiments. The results of the project have received international recognition as pioneering achievements.

3 FY2009–2013 Observation research program for the prediction of earthquakes and volcanic eruptions[2]

3-1 Unification of earthquake predictions and volcanic eruption predictions

The existing earthquake prediction program and volcanic eruption prediction program are set to be integrated in fiscal 2009 into a new observation research program for the prediction of earthquakes and volcanic eruptions[2]. Under the new program, earthquake predictions and volcanic eruption predictions will be coordinated from the viewpoints that "earthquakes and volcanic eruptions are natural phenomena that share the same geoscientific background, and joint observation research based on geodetic and seismological methods is useful in understanding both phenomena," and that "efficient and effective research can be conducted by effectively utilizing research resources, including earthquake and crustal deformation observation networks whose densities are unlike any other in the world, for observation research of both seismic and volcanic phenomena."

3-2 Volcanic eruption prediction research from FY2009

The volcanic eruption prediction programs implemented up to now and basic research based on the programs have led to the establishment of observation networks of active volcanoes, gradually allowing the detection and information transmission of abnormalities in volcanic activity. However, current volcanic eruption predictions are limited to predicting when a volcano "is likely to erupt" (timing) or that a crater is "likely to be formed around here" (location), and fall short of answering questions such as "How large will the eruption be?" (magnitude), "Will it be explosive or non-explosive?" (type) or "How long will it last?" (progression). Of the three stages of eruption prediction described in 2-1 (See 2-1), many volcanoes that are currently subject to observation are in Stage 1. Even some volcanoes that are active, have numerous eruption records, and are subject to multiple-factor observations and various surveys, are believed to remain in Stage 2. Substantive volcanic eruption forecasting requires reaching Stage 3. Based on such awareness of the current situation, the following directions have been indicated in the program starting in FY2009:

- **Strengthen volcano monitoring observation networks and conduct focused monitoring of areas with a high probability of volcanic eruption.**
- **Assess current volcanic activity and prepare eruption scenarios covering expected precursors and progression of an eruption.**
- **Establish a forecasting system that provides quantitative assessments of volcanic activity by combining monitoring results with models and eruption scenarios obtained from basic research.**

In the above, the keywords for research and development in the next program are: "Strengthening of volcano monitoring observation networks," "Preparation of eruption scenarios," "Creation of eruption mechanism models" and, eventually, "Establishment of an eruption prediction system."
The strengthening of volcano monitoring observation networks has seen steady progress, but the number of volcanoes on which the Japan Meteorological Agency conducts continuous observations is still limited to just over 30 of the 108 active volcanoes in Japan. Higher quality data need to be accumulated by conducting closer examinations in selecting target volcanoes and by introducing more factors (earthquakes, crustal deformation, volcanic gas, electromagnetic field, gravity, imaging, atmospheric pressure, etc.) in long-term, stable, continuous observations in order to identify the precursors of an eruption. Particularly in volcanic areas, high-density observations using observation wells are effective as signals are subject to large decays due to pyroclastic material.

Eruption scenarios are to be prepared based mainly on past records, describing the kinds of eruptions expected in the future for each individual volcano. They would indicate the changes with time, from the precursors all the way to the end of an eruption, the likely volcanic disaster phenomena and the extent to which the disaster might spread. The scenarios are expected to serve as a guideline for long-term risk management such as sediment control in areas surrounding a volcano, as well as for countermeasures once an eruption occurs.

From an eruption mechanism viewpoint, the goal is to create an eruption mechanism model that derives laws that govern eruption phenomena based on high-quality data and from the combined viewpoints of physics, petrology and chemistry. Volcanoes are an extremely complex system involving multiple states of solid, liquid and gas, and covering a wide range of scales, from the micro level such as magma bubble behavior to the macro level such as disaster-creating lava flows and fumes. Creating an eruption mechanism model is to create a model that describes how magma rises from underground and how it reaches eruption. As a qualitative image, the expansion of magma bubbles accelerates since magma pressure decreases as magma rises, leading to magma fragmentation and eventual explosion. In cases where the magma's gas component is low, the eruption is non-explosive, as seen in lava flows. Instead of such qualitative images, however, it is necessary to establish, quantitatively from observation data, a theoretical model for speculating the underground conditions, particularly the physical state, such as the vent's pressure and temperature immediately before an explosion.

It is thus necessary to aim to establish an eruption prediction system that involves the creation of an eruption mechanism model and preparation of an eruption scenario based on basic research such as the projects described above, coupled with high-quality data obtained through the strengthening of volcano monitoring observation networks, and conducting quantitative assessments of volcanic activity to enable predictions of future volcanic activity.

4 International cooperation and overseas research on volcanic eruption prediction

Volcanic eruption prediction efforts are conducted under international cooperation as well. Sharing observation data and knowledge of other volcanic countries in the world has greatly contributed to the advancement of Japan's volcanic eruption prediction technologies. At the same time, Japan's volcanic eruption prediction technologies centering on volcano observations have been introduced in volcanic countries in Southeast Asia and South America as part of Japan's international contribution and have produced positive results.

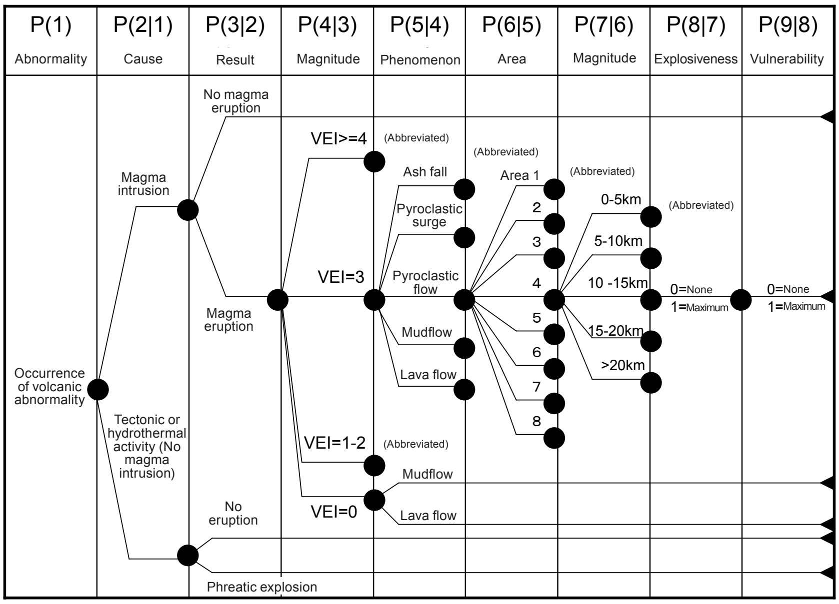


Figure 5 : Volcanic eruption event tree example

Prepared by the STFC based on Reference[17]

Much of the volcanic eruption phenomena depend on the properties of each volcano. It is unusual for disaster-causing eruptions to occur repeatedly in a single volcano. Furthermore, it is rare for a single human being to experience multiple eruptions during his or her lifetime. It is thus important to share volcanic eruption station information and observation data, particularly cases of abnormality detection. For this purpose, WOVO (World Organization of Volcano Observatories), an organization for volcanic research institutions and observation bodies around the world to provide data and share information, operates as a commission of IAVCEI (International Association of Volcanology and Chemistry of the Earth's Interior).[13] Notably, regarding observation data, the design of a shared database is moving forward under the WOVOdat project, a subordinate organization of WOVO.[14] The WOVOdat project is designed for member organizations to collaborate by aggregating data using a shared format and mutual referencing[15].

One of the pioneering efforts in the United States and Europe that is not used much in Japan is to treat eruption phenomena as probabilistic phenomena and calculate the probability of occurrence of each eruption disaster phenomenon.[16] As shown in Figure 1, volcanic eruptions are widespread, and an event tree shows volcanic phenomena generalized in terms of possibility, magnitude and branching (Figure 5). In each of the nodes in the event tree, the next branch of volcanic activity progression is considered and the eruption possibility is assessed from a probability standpoint. The probability calculation method is still being researched, but the method aims to be applied in both long-term and short-term assessments.

5 Volcanic disaster administration system

5-1 Volcanic disaster administration system of Japan

The findings of volcanic eruption prediction research are applied to volcanic disaster administration. The outline of volcanic disaster administration will be described in this section from the aspect of the societal significance of volcanic eruption prediction research.

Administrative judgments regarding volcanic disasters, similarly to other natural disasters, are basically made by the local government chiefs. Each local government draws up a basic plan for disaster prevention and, based on the plan, implements administrative measures such as evacuation, goods supplies, and reconstruction in the event of volcanic disasters. If the disaster spreads across a wide area and cannot be handled by municipal governments alone, the process is upgraded to the prefectural government or national government levels. At the national government level, the Cabinet Office (disaster prevention section) is responsible for coordinating between related ministries and agencies (Figure 6). Needless to say, the volcano disaster administration expects volcanic eruption prediction research to provide accurate and clear information regarding the possibility of volcanic eruptions and activity forecasts.

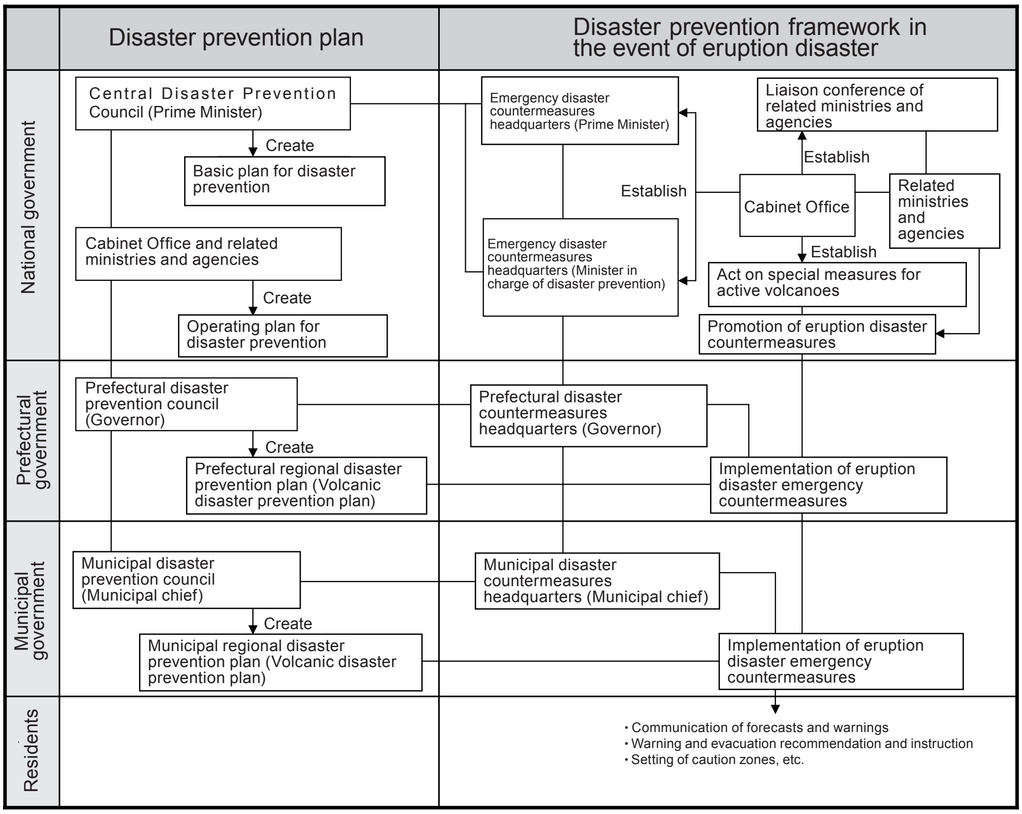


Figure 6 : Volcanic disaster administration system of Japan

Prepared by the STFC based on Reference[5]

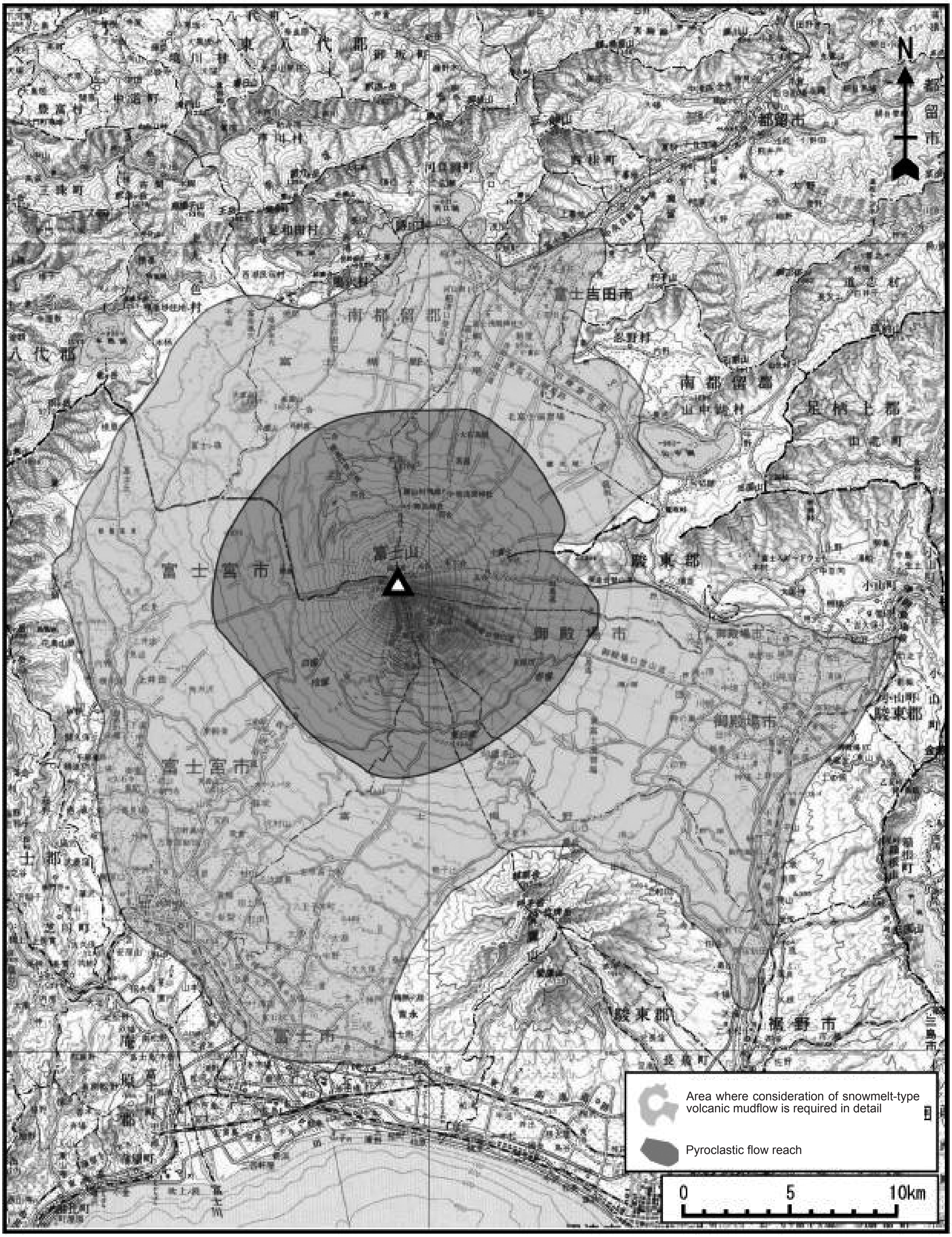
5-2 Volcanic disaster prevention hazard maps

As part of local disaster prevention planning, increasingly more volcanic disaster prevention hazard maps are being created in recent years. A volcanic disaster prevention hazard map shows disaster prevention information including the spread of damage following possible volcanic activity such as an eruption, evacuation centers, and evacuation routes, and serves as the foundation of disaster prevention countermeasures (Figure 7). Committees comprising local governments in the area concerned have taken the initiative to create a hazard map based on information such as simulations of various phenomena, and distributed the map to provide information to residents. Such hazard maps have been prepared for 37 volcanoes in Japan, and they can be viewed online at the National Research Institute for Earth Science and Disaster Prevention's website.[18]

When Mt. Usu erupted in 2000, evacuation was conducted smoothly, as residents and disaster prevention organizations were informed of the volcanic disaster prevention hazard map in advance. At Mt. Fuji, concerns grew of the possibility of the first eruption in some 300 years due to active deep low-frequency earthquakes with epicenters at depths of around 10–15km between October 2000 and May 2001. But the Coordinating Committee for Prediction of Volcanic Eruptions judged that an eruption was not imminent, as changes in epicenter depth and crustal deformation abnormalities could not be detected. However, the event led to renewed awareness that Mt. Fuji was an active volcano and highlighted the need for assessing the direct impact of volcanic disasters in the Tokai region, Japan's main artery, as well as the Tokyo metropolitan area, and the need for adopting countermeasures. Responding to these needs, the Mt. Fuji Hazard Map Examination Committee (now Mt. Fuji Volcano Disaster Management Conference) was established by the national government and local authorities under the command of the Cabinet Office, and a report was compiled in June 2004.[19]

5-3 Eruption warnings and eruption alert levels

The Japan Meteorological Agency began issuing forecasts and warnings on volcanic phenomena in December 2007, and eruption alert levels have since been introduced in 20 volcanoes (Table 3). Before then, emergency information on volcanic activity, the equivalent of alerts and forecasts in a weather forecast, was provided. However, the revised



(Pyroclastic flow reach is indicated in dark grey, and snowmelt-type mudflow reach is indicated in light grey.)

Figure 7 : Volcanic disaster prevention hazard map example

Source: Reference[19]

Table 3 : Eruption warnings and alert levels announced by the Japan Meteorological Agency

Abbreviated Term	Target area	Levels & Keyword		Explanation		
				Expected volcanic activity	Action to be taken by inhabitants	Action to be taken by climbers
Warning	Residential areas	Level 5	Evacuate	Eruption that may cause serious damage in residential areas, or imminent eruption.	Evacuate from the danger zone. (Target areas and evacuation measures are determined in line with current volcanic activity).	
Warning	Residential areas	Level 4	Prepare to evacuate	Possibility or increasing possibility of eruption that may cause serious damage in residential areas.	Prepare to evacuate from alert areas. Let disabled persons evacuate. (Target areas and evacuation measures are determined in line with current volcanic activity).	
Near-crater Warning	Non-residential areas near the crater	Level 3	Do not approach the volcano	Eruption or possibility of eruption that may severely affect places near residential areas (threat to life is possible in these areas).	Stand by, paying attention to changes in volcanic activity. Let disabled persons prepare to evacuate in line with current volcanic activity.	Refrain from entering the danger zone. (Target areas are determined in line with current volcanic activity).
Near-crater Warning	Around the crater	Level 2	Do not approach the crater	Eruption or possibility of eruption that may affect areas near the crater (threat to life is possible in these areas).	Stay as usual.	Refrain from approaching the crater. (Target areas around the crater are determined in line with current volcanic activity).
Forecast	Inside the crater	Level 1	Normal	Calm: Volcanic ash emissions or other related phenomena may occur in the crater (threat to life is possible in these areas).	Stay as usual.	No restrictions. (In some cases, it may be necessary to refrain from approaching the crater).

Source: Reference[20]

Meteorological Service Act (December 1, 2007) took into consideration the distance from the assumed crater to residential areas, in addition to the risk of eruption, and clarified the affected areas in the event of an eruption as well as necessary disaster prevention measures. Key phrases such as “Evacuate,” “Prepare to evacuate” and “Do not approach the volcano” are set for each danger level. However, while these eruption warnings and alert levels are pioneering efforts, they are also premature in the sense that the observation system and assessment methods used to judge and provide information are still in the trial-and-error stage. Future improvements in accuracy are thus required.

6 Issues and proposals regarding future volcanic eruption prediction research and volcanic disaster prevention administration

The 35-year-old volcanic eruption prediction program has reached a turning point and, as described in 3-1, will be reorganized into an observation research program for predicting earthquakes and volcanic eruptions, to be implemented in tandem with earthquake prediction programs. Since volcanic activity and seismic activity are closely related, the new program is expected to be highly effective in terms of the mutual use of information gained from both the earthquake and volcano fields. The Central Disaster Prevention Council clearly positions eruption forecasts and other volcano information released by the Japan Meteorological Agency as the base point of disaster prevention measures, and considers measures in accordance with the volcano information. This means that the importance of more sophisticated and accurate volcano information is growing.

In reality, however, the following two major problems remain:

① **Volcanic eruption prediction research is still in the developmental process in terms of identifying the eruption mechanism principles, and the prediction accuracy is varied.**

② **The observation framework is vulnerable, with the observation network of the Japan Meteorological Agency (the organization**

responsible for forecasts) alone unable to grasp volcanic activity with high reliability. In addition, universities, which have cooperated in observation efforts, are facing a crisis regarding the continuation of observations.

In this chapter, proposals will be made regarding the future direction, taking into consideration the background of the above problems.

6-1 Efficient observation system leading to volcanic eruption predictions

In volcano observations, not only are earthquake and crustal deformation observations necessary, but so are continuous observations of multiple factors, including electromagnetic fields, gravity, volcanic gas and visible images. Therefore, improving the above factors collectively and accumulating high-quality data are the basics of abnormality detection and the straightforward approach to realizing volcanic eruption prediction.

However, regarding the volcano observation system, the Ministry of Education, Culture, Sports, Science and Technology has indicated that, starting in 2009, the number of volcanoes subject to focused observation within the volcano observation networks of national universities nationwide, which have served as the foundation of volcanic eruption prediction research, will be reduced sharply from 34 to 26 that have the possibility of eruption.[21] Furthermore, national university corporations have faced cuts in research budgets and staff following their transformation into corporate entities, rendering some unable to update aging volcano observation equipment or maintain volcano observation facilities.[22,23] If the reduced observation networks are subsequently abolished, the detection of abnormalities necessary to capture the precursors of an eruption is not possible, raising concern that, most importantly, volcanic disaster risks cannot be identified.

As mentioned in Chapter 5, the eruption alert levels introduced by the Japan Meteorological Agency provide information regarding specific volcanic disaster prevention guidelines, such as evacuation, and the information needs to be highly credible, backed by sufficient data and interpretation. However,

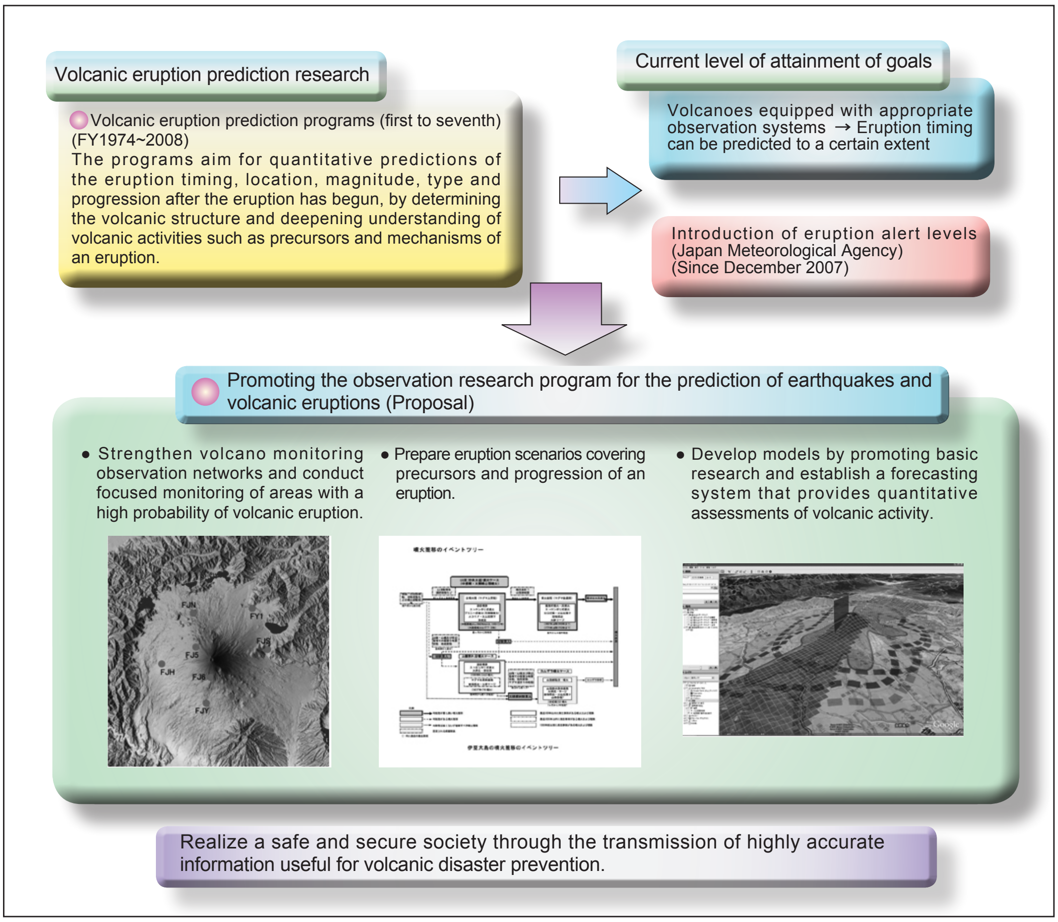


Figure 8 : Direction of future volcanic eruption prediction research

Prepared by the STFC based on References[2,24] the observation data supporting the information are highly dependent on the observation networks of national university corporations. It cannot be denied that an observation framework comprising the Japan Meteorological Agency alone might lead to deterioration in quality. In addition, national university corporations have built close relationships with local authorities and residents in their respective volcanic areas, and have a wealth of experience and buildup in terms of sharing and utilizing volcanic activity information. A cutback in national university corporations' observation framework might diminish some of the close locally based partnerships. Thus, the observation research program for the prediction of earthquakes and volcanic eruptions is faced with a dilemma; while it emphasizes the importance of observations as the foundation of volcanic eruption predictions, in reality a reduction of the observation framework is inevitable.

Faced with such circumstances, it is necessary to promote volcanic eruption prediction research more effectively than ever in accordance with the direction indicated in the observation research program for the prediction of earthquakes and volcanic eruptions, in order to minimize the negative effects of the overall downsizing. Figure 8 sums up this point. In terms of strengthening volcano monitoring observation networks, it is important to utilize existing infrastructures that have been established in past earthquake survey research as effectively as possible—such as the Geographical Survey Institute's GEONET, a GPS-based observation network, and the National Research Institute for Earth Science and Disaster Prevention's Hi-net and other data transmission systems, which are foundation observation networks of micro earthquakes. This is necessary to realize the establishment and operation of dense and multiple-factor volcanic foundation observation networks on a permanent basis. By making use of them, six to 10 observation stations can be provided around a volcano on a satellite basis. In addition, aged observation facilities of universities should be reviewed from the perspective of whether or not they can be part of a foundation observation network, and an overall redesigning of a foundation observation network, including the university facilities, is needed.

6-2 Construction of eruption models and eruption scenarios

Basic research on creating an eruption model by physically identifying the eruption mechanism is essentially the means for volcanic eruption prediction. In particular, regarding the mechanism of magma rising from underground followed by ejection and explosion, a highly accurate theoretical model can be constructed by conducting laboratory experiments and simulations to examine processes such as the behavior of magma gas components and the fragmentation mechanism, and verifying the results against high-quality data obtained from foundation observation networks.

In addition, an eruption scenario—designed to directly contribute to volcanic disaster prevention—would be useful, particularly as information for emergency measures, if the concept of progression over time is added to the event tree of volcanic eruption phenomena (Figure 5). The key to creating such a scenario lies in the sophistication of geological techniques, such as boring and trench techniques, as well as simulation technology of lava flows, pyroclastic flows and fumes. By putting together data from foundation observation networks, eruption models and eruption scenarios, the establishment of a highly reliable eruption prediction system would eventually become possible. By incorporating the probability-based approach tried in the United States and Europe, and by utilizing an internationally shared database on abnormal phenomena, the creation of an eruption scenario with higher accuracy should be pursued.

6-3 Provision of highly accurate and useful volcanic disaster prevention information

Since it first began issuing eruption warnings and eruption alert levels, the Japan Meteorological Agency has provided not only information about volcanic activity but also specific volcanic disaster prevention information such as evacuation conduct. In this pioneering effort, basic research has led directly to volcanic disaster prevention. However, since the measure was introduced when the development of volcanic eruption prediction technology principles was still in progress, it is important to use the information with the full understanding that, at present, there remain limitations in terms of its accuracy. In addition, it is essential to enhance information accuracy in the future through the continuation of basic research and strengthening of the observation system. At the same time, in addition to taking measures to protect the safety and security of the lives of residents in areas near volcanoes—such as providing health hazard information and offering psychological care to help cope with eruption damage and evacuation life—more detailed considerations, such as the evacuation of pets and livestock, are believed to be necessary in the future.

Of the various natural disasters, volcanic eruptions are a particularly complex phenomenon and, once an eruption occurs, depending on its magnitude, even remote areas can be affected considerably by fumes and ash falls, and a massive eruption could have an impact affecting the entire planet. Particularly in Japan, where coexistence with volcanoes is necessary, it is absolutely vital to provide short-term volcanic eruption prediction information with enhanced accuracy and reliability without delay, as well as to conduct long-term volcanic risk assessments, for the safety and security of people's lives.

Acknowledgement

In writing this article, I received valuable opinions from Prof. Toshitsugu Fujii of the Earthquake Research Institute, University of Tokyo, also chairman of the Coordinating Committee for Prediction of Volcanic Eruptions, and from Mr. Motoo Ukawa, director of the National Research Institute for Earth Science and Disaster Prevention's Volcano Research Department. I would like to take this opportunity to extend my deepest gratitude to both of them.

References

[1] Japan Meteorological Agency website：http://www.seisvol.kishou.go.jp/tokyo/volcano.html

[2] About the promotion of the observation research program for the prediction of earthquakes and volcanic eruptions (proposal)：http://www.mext.go.jp/b_menu/houdou/20/07/08071504.htm

[3] Y. Hayakawa, Elekitel series: Japan's volcanoes-a new outlook, No. 6 Izu-Oshima：http://elekitel.jp/elekitel/series/2003/03/sr_03_n.htm

[4] Japan Meteorological Agency volcanic operation document, Twenty-Year History of the Coordinating Committee for Prediction of Volcanic Eruptions (1995).

[5] Cabinet Office (disaster prevention section), web page on volcanic disaster prevention：http://www.bousai.go.jp/kazan/kazan.html

[6] Sixth volcanic eruption prediction program: http://www.eri.u-tokyo.ac.jp/predict/kazan98.html

[7] Seventh volcanic eruption prediction program：http://www.mext.go.jp/b_menu/shingi/gijyutu/gijyutu0/toushin/03072402.htm

[8] Review of the status of implementation of the seventh volcanic eruption prediction program (report)：http://www.mext.go.jp/b_menu/shingi/gijyutu/gijyutu6/toushin/07011909/001.htm

[9] T. Shimizu, Establishment of a Disaster Prevention Satellite System in Asia and Promotion of International Cooperation, Science & Technology Trends, No. 80 (2007).

[10] Cosmic-ray Muon Radiography Imaging of Volcanic Interiors, Science & Technology Trends, No. 78 (2007).

[11] Special coordination funds for promoting science and technology, Accomplishment report, Promotion of leading research, Multidisciplinary approach on volcanic activity of Fuji Volcano and advancement of related information：http://scfdb.tokyo.jst.go.jp/pdf/20011970/2003/200119702003rr.pdf

[12] Y. Ida and H. Taniguchi, Closing in on Volcanic Explosions: Identifying the Eruption Mechanism and Reducing Volcanic Disasters, University of Tokyo Press.

[13] WOVO：http://www.wovo.org/

[14] WOVOdat：http://wovo.atmos.colostate.edu/logon.html

[15] Schwandner, F. et al., WOVOdat：The world organization of volcano observatories database of volcanic unrest, Cities on Volcanoes 5, (2007).

[16] Marzocchi et al., 2008 W. Marzocchi, L. Sandri and J. Selva, BET_EF: a probabilistic tool for long- and short-term eruption forecasting, Bull. Volcanol 70 (2008), pp. 623-632.
[17] Newhall and Hoblitt, 2002 C.G. Newhall and R.P. Hoblitt, Constructing event trees for volcanic crises, Bull. Volcanol 64 (2002), pp. 3-20.
[18] National Research Institute for Earth Science and Disaster Prevention, volcanic disaster prevention hazard map database: http：//www.bosai.go.jp/library/v-hazard/
[19] Mt. Fuji volcanic disaster prevention measures：http://www.bousai.go.jp/fujisan/
[20] S. Kitagawa, Operation of eruption alert levels and related efforts, Japan's new volcanic disaster prevention structure—eruption warnings, eruption alert levels and evacuation system in the event of an eruption, Volcanological Society of Japan 2008 autumn convention public symposium speech draft.
[21] The Asahi Shimbun, December 8, 2008.
[22] T. Fujii, Current status and issues of volcanic eruption prediction programs, Geological Survey of Japan 9th symposium, National Institute of Advanced Industrial Science and Technology：
http://www.gsj.jp/GDB/openfile/files/no0470/0470-4.pdf/
[23] T. Fujii, International workshop on measures to reduce volcanic disasters 2005—Lessons of volcanic disaster prevention measures to be learned from overseas cases—report, pp. 279-289.
[24] Y. Morita et al., Volcanic eruption prediction system based on eruption scenarios, Symposium on earthquake and volcanic eruption prediction research program：
http://www.eri.u-tokyo.ac.jp/YOTIKYO/nenji/sympo2008.html

Profile

Eisuke FUJITA
Affiliated Fellow, STFC
Deputy Director, Volcano Research Department,
National Research Institute for Earth Science and Disaster Prevention
http://www.bosai.go.jp/

Specializing in volcano physics, Fujita engages in volcanic activity modeling based on volcano observation data and numerical simulations of volcanic phenomena. The simulation chart predicting the area of lava flow in a volcanic eruption is used in the creation of hazard maps.

(Original Japanese version: published in January 2009)

8

The Role of Operations Research towards Advanced Logistics

EIZO TAKAI
Affiliated Fellow

1 Introduction

Product supply chains of recent Japanese industries are now at a major turning point in two major aspects, namely, structural changes in the nature of supply chains and more advanced functional requirements. Structural changes have been brought about by various circumstances, including the more complex and geographically wider international logistics associated with the globalization of corporate activities, a change in the relationships between companies from the simple serial procurement/supply chains of the past to open network-type supply chains, and changes in modes of logistics due to expansion of e-business accompanying the development of information and communications technology (ICT), among others. On the other hand, more advanced functional requirement levels are the result of shortening of product model change cycles and the need for adaptability to rapidly-changing markets, rationalization and energy conservation in response to high energy costs, and the like. The importance of the more advanced supply chains resulting from the progress of globalization is emphasized in this year's "White Paper on Monodzukuri (Promotion Policy for Basic Technologies in Monodzukuri in FY2007)."[1]

These requirements mean, in other words, that innovation and more advanced techniques are demanded in logistics in supply chains.

In realizing innovation and more advanced techniques in logistics, use of more advanced and sophisticated information technology is necessary. In this meaning promotion of the practical application of Operations Research (OR) is strongly required, as well as the development of more sophisticated OR theories and methodologies. Although improvement of hardware, such as transportation facilities and the infrastructure, is also important, problems will not be solved without more advanced planning and operation management systems using advanced software technologies and optimization methodologies. In rational planning of the highly complex distribution network as a whole, optimization of factory and warehouse location, and optimization of transportation routes by using OR is indispensable. In order to respond to recent business environment with rapidly-changing markets, and continual entry of new products an efficient operating system with flexibility and speed achieved by OR is demanded. The evolution of logistics is not limited simply to progress in hardware in the form of automation of warehouses and transportation facilities; progress and adaptation of OR techniques are also extremely important.

Furthermore, as recent challenges, high expectations are placed on innovation by service science as a means of increasing productivity and improving quality in the service industry, which now accounts for a major part of the industrial structure. As an important object of research in this field, logistics is considered to be an extremely promising area.

This report focuses on research and development of logistics design for realizing more advanced supply chains, the importance of which has been pointed out in the above-mentioned "White Paper on Monodzukuri." The concepts and current problems of supply chains and logistics are introduced, and secondly the proper roles of OR in solving the current and future logistics problems are discussed. Finally, the primary issues for the promotion of research on logistics and OR in Japan in the future are proposed.

2 Challenges and problems for logistics in Japan

2-1 Development of logistics in supply chains and related issues

The concept of "physical distribution," meaning the activities of distribution and inventory of the raw materials and products which support the real economy, has a long history. The movement of improving and rationalizing such activities through economic and technical research has been accelerated particularly in the United States since the end of World War II. The concept of "physical distribution management" appeared following World War II, and evolved into the concept of "logistics" as a new business model representing a fusion of physical distribution and information systems. In Japan, these two terms are used virtually synonymously, but properly speaking the former is a concept that focuses on the individual work of movement (transportation) and storage of goods, while the focus of the logistics is the rational design, management, and operation of distribution as a whole utilizing information. "Logistics" is originally a military term meaning the activities of supplying required troops, weapons and ammunition, provisions, etc. in accordance with tactical plans. Thus, the analogous activities in the field of economics were sometimes termed "business logistics." Quoting the definition of the Council of Logistics Management (CLM; now the Council of Supply Chain Management Professionals, CSCMP),[2] "Logistics management is the part of supply chain management that plans, implements, and controls the efficient, effective forward and reverses flow and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customers' requirements." [2]

The activities in logistics, include inventory management, transportation management, warehouse management, material handling, packaging, returns/recovery in general, In some cases, such activities as demand forecasting, order management are also included. In addition to these, Lambert [3] mentions some other activities as plants and/or warehouse location design, customer service, procurement, parts/service support, and others. While top management function of logistics, CLO (Chief Logistics Officer), is just started to be recognized in Japan, this management function is already established in the United States. From this, one may say that the function of logistics is considered to be much larger and important in the United States than in Japan.

The concept of "supply chain" appears in the above-mentioned definition of logistics, and indicates the series of activities for supplying goods and services from procurement of raw materials to the final customer, through the chain of activities of production, sales, and distribution. The basic concept of traditional transportation business development is "correct delivery of products" for a single company or product. Differs from the concept of former simple transportation of single goods, the concept of "supply chain" is to create and provide final value to consumers considering wider range of integrated corporate activities starting from raw materials to final products, R&D and CRM. The concept of a "supply chain" was further expanded by the concept of Supply Chain Management (SCM) starting from 1990s that intend to realize new, rational business process through the integration of business activities clearing the boundaries of different business divisions and/or companies.

Figure 1 shows the general concept of a supply chain.[4] The totality in which the activities of central companies and the various related companies in the process from raw materials to the final consumption are combined by flows of business, information, and products/services (raw materials, parts, products, goods) forms entire supply chain. The solid line arrows in the figure show the flows of products from upstream to downstream, while the broken line arrows show the major flows of information such as order issuance, demand, etc., which run from downstream to upstream. It also shows that the supply chain is constrained by the capabilities of the member organizations in various factors such as the production or processing capacity, specialties, information, capital, human resources, etc. The aim of SCM is to realize more advanced supply chain by increasing the productivity, efficiency, and effectiveness of this system as a whole through establishing appropriate memberships, well balanced capabilities, and information connection.

SCM is a management methodology developed in the 1990s. Its aim is to create an efficient operation system by eliminating overproduction and shortages

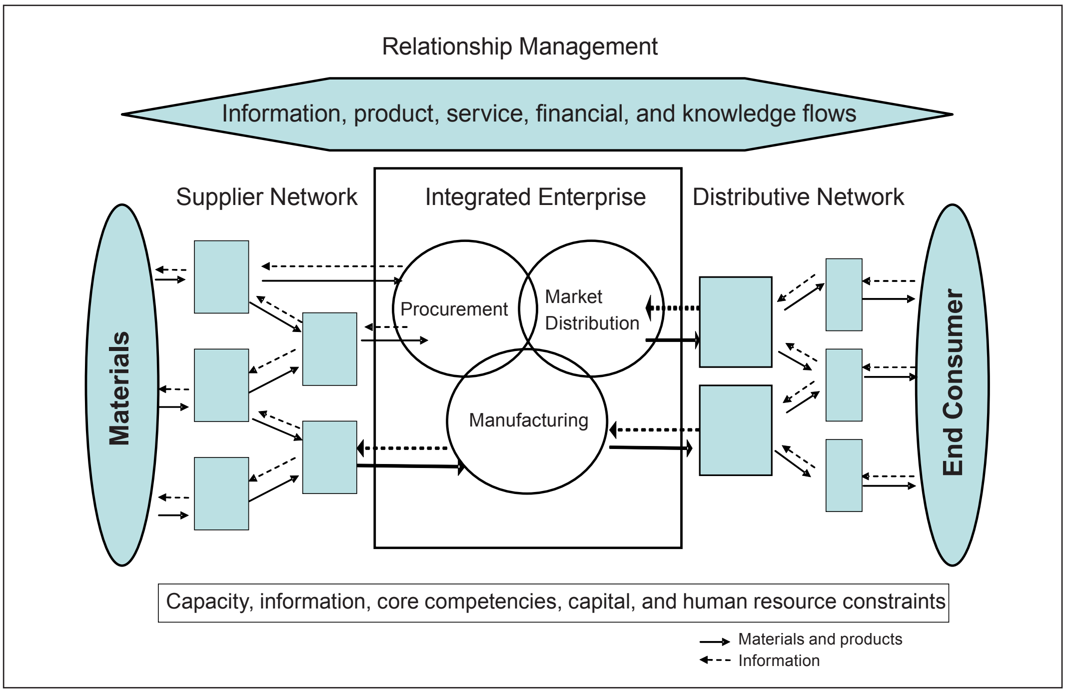


Figure1 : Generalized supply chain model

Prepared by the STFC based on reference [4]

to cope with rapidly changing volatile market situation , where conventional production planning based on traditional demand forecasting is not appropriate This is to be achieved by rational combination of production and logistics management at the same level. Its basis is reconsidering the whole business process across the barriers between organizations and integrate it as a single stream. In a sense, SCM has accelerated such changes as the shortening of product life cycles and the evolution of the internationalization of product manufacturing. In other words, in the era of physical distribution, supply chains were consisted of simple transportation connecting the inventories distributed all of the stages from source suppliers, production plants, warehouses, and retail stores. SCM is a methodology of transforming supply chains by connecting final consumer to the suppliers directly eliminating intermediate inventories as far as possible and provide efficiency with shortening of lead time.

The success achieved by the integrated model of the business process called QR (Quick Response), which enabled the rebirth of the apparel industry in the United States, is considered to be the beginning of the concept of SCM.[5] That success made it popular and many models of various names using various techniques were then conceived by the pioneers as Dell Corporation, Wal-Mart, and others. Although a variety of methodologies were proposed, their aims can be summarized as shortening of supply lead time, avoidance of defects, reduction of wasteful overproduction and excess inventories by sharing downstream information (demand side) with the upstream process, and controlling the upstream process on this basis. With the above-mentioned QR, the American domestic apparel industry succeeded in shortening the total process, which originally had required 56 weeks from thread for weaving to the finished product, to 12 weeks by realizing flexible production scheduling coupled to market information, shortened production lead time and shortened inventory turn around time of materials and semi products, etc. This represented the establishment of a business model which made it possible to supply products quickly in line with market trends, while greatly reducing total stocks, and introducing new products within a short time. This made it possible to compete successfully with imported cloths, which only had the advantage of low production cost. The implementation of this model was the occasion for the birth of the new type of apparel companies with worldwide retail networks. The concept that “downstream controls upstream” is also the basis for the world-renowned model called the “Toyota kanban system.” and JIT (Just-In-Time) procurement.

Today, SCM has developed into a concept covering wide range of operation design and management including product design to customer relationship management. However, its basis is still on the establishment of closer coordination of the information flow and operational workflow in production and logistics. Accordingly, the heart of the system lies in logistics.

As mentioned previously, the focus of this report is research and development related to designing logistics. Figure 2 shows the major issues in logistics existing among the major stakeholders in a supply chain. In this figure, although the problems in actual logistics are more congested, one may recognize that the importance of establishing plans in all operational flows and management levels, from strategic decision-making to routine operational control. As classified very broadly in Figure 2, the main issues in the planning can be divided into (1) issues related to international logistics, (2) issues in the location problems and network design for production plants and warehouses, (3) issues in the inventory management and inventory allocation in the network, (4) issues on the decision of transportation route, modal selection, vehicle assignment., (5) other related issues such as demand forecasting, cargo loading, labor management, etc. In addition, recently, as a combination of the above mentioned problems, issues of green logistics, including greenhouse gas reduction, conservation and recycling of materials, have also become important

In establishing the various types of plans shown in Figure 2, it is necessary to pursue optimality by using diverse data in many cases under various external conditions. In order to obtain rational optimum plans for these diverse and complex problems, application of mathematical techniques using OR is demanded. Moreover, research and development of more advanced techniques corresponding to the complexity and larger scale of problems is also necessary. These problems are discussed in Chapter 3.

2-2 Recent problems in logistics in Japan

As discussed at the outset, supply chain of Japanese industry is now facing major turning points, and rationalization and advancement of logistics is a crucial issue for strengthening the foundations of monodzukuri (art of manufacturing) in Japan to cope with the various problems such as the ever widening international logistics, requirements for higher market adaptability, economic pressure for rationalization, and satisfying energy conservation and environment-friendliness needs. All of these requirements are the keys to the procurement of raw materials and parts

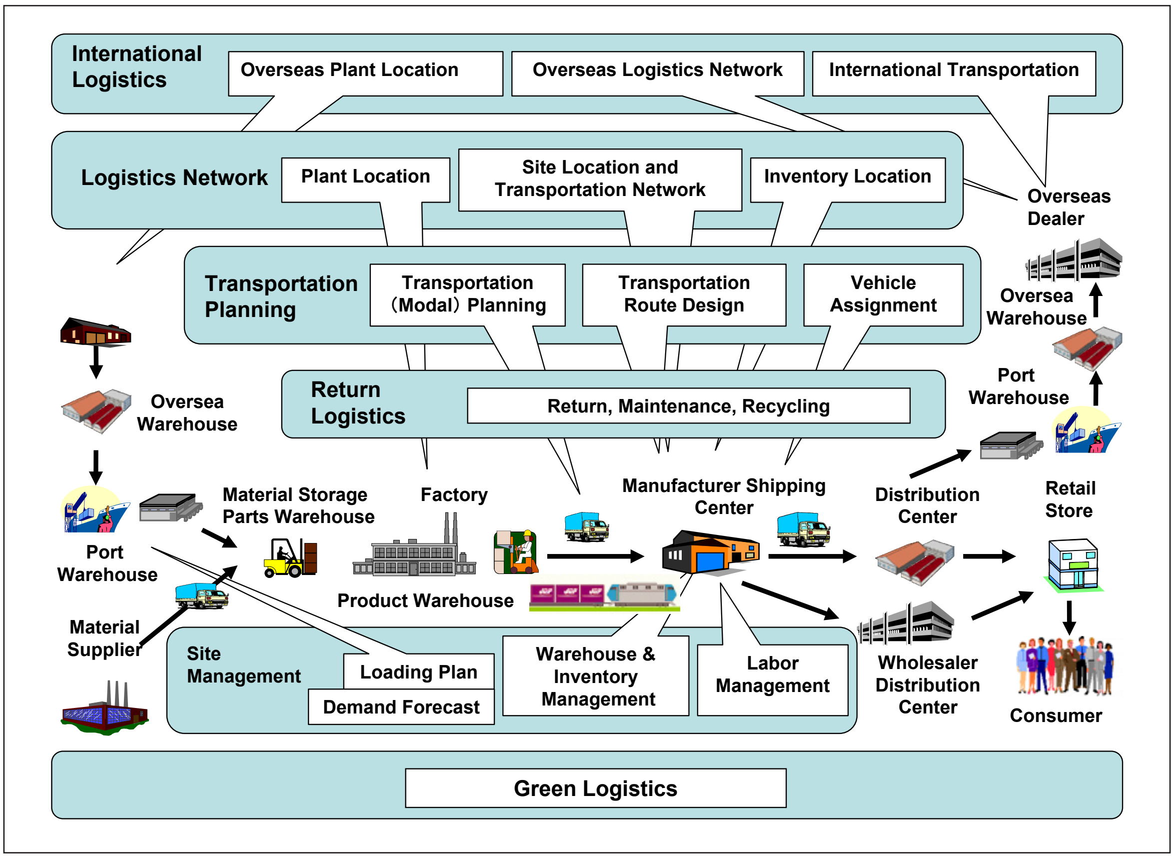


Figure2 : Major issues in logistics planning and management

Prepared by the STFC

and product supply to the market. Internationally, the development of a large-scale land transportation network extending from northeastern Asia to India, the Middle East, and Europe ("Eurasian Land Bridge") is considered likely in the future. Therefore, research on policies for strengthening Japan's international competitiveness, such as cooperation and contribution toward the realization of international transportation systems including these regions, is also an important issue.

The total amount of logistics costs in Japan's domestic industries is approximately ¥42 trillion/ year (2005), amounting to about 8% of this country's gross domestic product (GDP).[6] Technical progress can be seen in this field, as exemplified by the use of advanced material handling tools, transportation facilities and RFID, and improvements have been realized in the software aspect, such as popularization of inventory optimization software and transportation management systems. However, the labor productivity in this sector is still low. According to the "International Comparison of Labor Productivity (2006)" published by the Japan Productivity Center for Socio-Economic Development.[7] Japan's labor productivity in the logistics sector is approximately 50% of that of the United States. Thus, further rationalization is strongly demanded in this sector.

It has been pointed out that the possible causes of this low productivity may include various factors, the as-delivered pricing system, which is a unique business custom in the logistics and sales industries in Japan (system in which the cost of transportation to the customer is included in the price of the product; because this makes the cost of distribution a latent factor, it is considered to be a cause of low consciousness of rationalization in distribution), delivery with small lot and high frequency due to the small storage space of stores, strong preference of consumers on freshness, requirements for large variety of goods, and other cultural factors. However, there is also an opinion that one big factor is strict quality requirements on delivery in Japan (on-time delivery rate, order fulfillment rate, less damage rate, etc.), which are without parallel in other countries. For example, according to the recent research, the on-time delivery rate in the United States is approximately 90%, but in contrast, the rate in Japan is 99.99%.[8] This undoubtedly supports highly efficient production in Japanese manufacturing factories, but on the other hand, the possibility that this increases delivery costs by requiring the same accuracy in areas where strict on-time delivery is not necessarily essential has also been pointed out.

In the distribution costs of ¥42 trillion mentioned previously, nearly 70% is costs associated with transportation. Due to heightened interest in so-called green logistics, the main purpose of which is reduction of CO_2 emission demanded by global warming countermeasures in recent years, and the necessity of energy and fuel saving on transportation due to the spike in the oil price, interest in rational transportation technology and delivery systems is extremely high. Research on the solutions involving a combination of transportation methods, such as land transport by truck and rail, sea transport, air transport, etc., which is termed multi-modal transportation, is a promising area on this problem. In order to realize this rationally, R&D activities should not be limited on hardware, but also should include optimization planning using advanced mathematical techniques by OR to realize complex and large scale logistics.

Needless to say, the effects of changes in the supply chain will extend to industry as a whole. Rationalization in logistics is not a problem only for the logistics industry (transportation and shipping industry, forwarders, warehousing industry, 3PL (third-party logistics)) in the service industry sector; its necessity in manufacturing industries and the energy industry is also increasing.

In the logistics planning's shown in the Figure 2, there are areas where advanced techniques have already been accepted. However, considering the effect of changes in the supply chain as a whole, solutions to problems which are difficult for the private sector alone, such as optimum design of large-scale international transportation networks, including their operation, development of advanced technologies for realizing green logistics, and the like, are expected in specialized research institutions such as universities. Chapter 3 describes problem-solving techniques using OR and the necessary research and development to solve the important focused problems for which effects are expected.

3 Advancement of logistics by OR and expected research fields

In a complex activity like logistics, problem solving by assumptions of a simple cause-and-effect relationship alone is not sufficient. Optimum plan should be derived through the analysis and comparison of many alternative case studies simulating the behavior of logistics organization or processing system under the premises based on present situations or future planning. This means that application of the OR methodology based on mathematical process is strongly required.

3-1 Development of OR and logistics

OR (operations research) was born as operational research, which is a technique corresponding to technical research, in order to make effective use of new military technologies such as radar, night fighters, underwater mines, etc. in the United Kingdom in the final stage of World War II. Subsequently, the concept migrated to the United States, where it developed under the name of operations research (in this case, tactical operation research), and provide a wide range of achievement, from frontline military operations as such to logistical support in behind. After the war, this technology was made available to private business sectors and was widely applied in various industries, evolving into the OR of today.

Many definitions have been given for OR. In general, however, as shown in Figure 3, the term indicates a methodology in which corporate and social activities producing goods and services are understood as a system which outputs results when inputs are given, the system of those basic activities is constructed as a mathematical model, and problems regarding the operational methods of the system are analyzed using mathematical tools conforming to the purpose in order to produce the optimum solution. In practice, the problem finding and derivation of solutions are carried out by using a variety of techniques, such as mathematical and statistical analyses, system simulations, optimization algorithms, etc.

From the very start of its development, OR had a strong relationship with problems related to logistics. Many of the basic technologies in the initial stage have also become basic technologies of logistics planning, even today. That is, the basic technologies of demand forecasting, inventory theory, determination of optimum order quantity (economic order quantity), shortest path planning, mathematical programming methods (resource allocation problems, optimal location problems), queuing theory, discrete

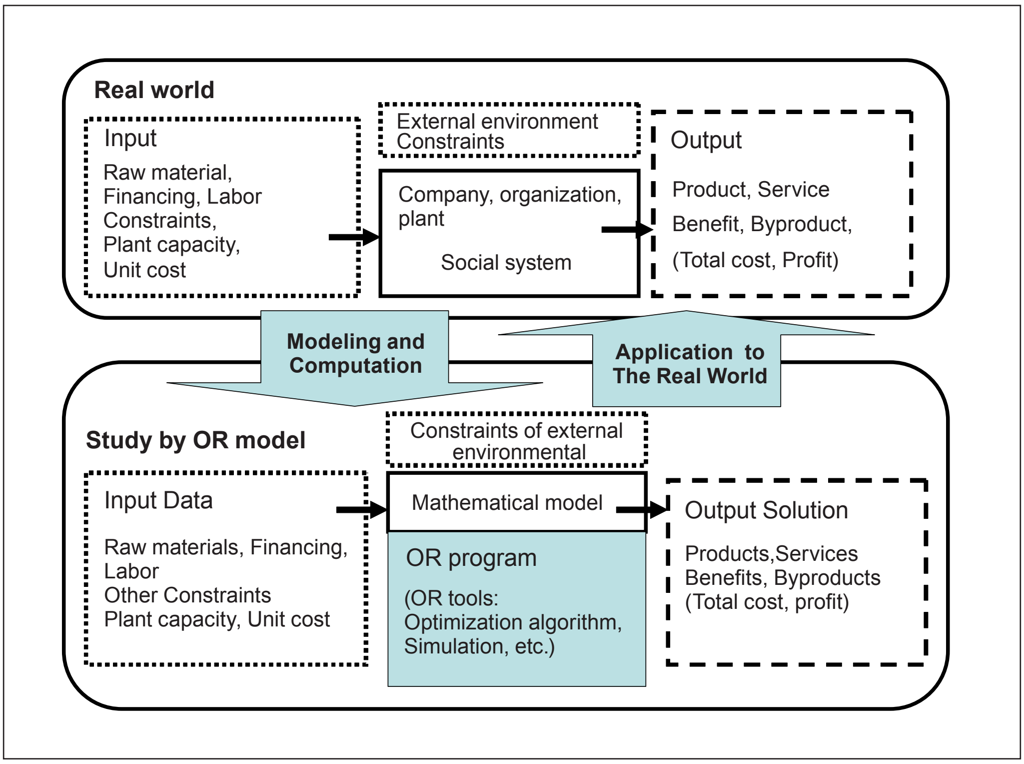


Figure3 : Concept of study by OR model

Prepared by the STFC

simulation, etc. were researched as problem-solving techniques.

OR is an academic discipline which has already produced successful results in the real world, but like other fields of research, it is also one where evolution is constantly demanded. Since its birth, OR has continued to develop and evolve by developing new solution methods as a science for problem-solving in management and planning, which is always unified with practical business in dealing with new problems. As a result, the cycle of opening new situations for application by the development of new theories has continued to bring about further progress.

In an example related to logistics, the remarkable drop of airline fares in recent years is a result of adopting rational fleet operation scheduling using state of art planning techniques. It had long been understood that large-scale mathematical models for this type of problems could be solved by integer programming method, there was no method of solving large-scale integer programming problems with a model size exceeding one million variables at a practical speed and the application of the technique was limited to small partial planning models. The breakthrough was made by the algorithm develops by Narendra Karmarkar of AT&T's Bell Laboratories (at the time). (AT&T was granted a patent for the Karmarkar algorithm. As this was the world's first patent for a mathematical equation, it caused a controversy argument on the patentability of equations over the world).[9] Today, many practical methods to solve this type of problems have been proposed and commercially available in the form of optimization software, and are widely used in the planning for semiconductor production, optimization of the logistics network, and similar problems.

Penetration of OR in the logistics field in Japan is still in behind with Europe and the United States. One reason for this is the fact that virtually not much practical research has been conducted in universities. In Europe and the United States, research on and the establishment of logistics strategies using OR is carried out widely as joint research by universities and private companies and/or public organizations, and the results of the research are often made public in journals and presentations at academic conferences, etc., including the results of research and implementation by private companies. However, in the Japan, there is little awareness of the importance of this. Not only collaboration between companies and universities are rare, but companies also tend to avoid publication of data and results to a greater extent than is actually necessary. As a result, there have been delays in a variety of aspects, including practice, R&D, and the training of skillful people with advanced knowledge and application capabilities in companies. Although Japan has many outstanding researchers, it is unfortunate that their work has been limited to theoretical study in the laboratory. The development of policies that overcome this condition is demanded. The author hopes to see the establishment of policies which activate research and development in connection with practical problems and research issues desirable to promote from a policy standpoint, as will be discussed in the following and sharing of the results by industry and universities. Logistics in Japan has achieved a unique development suited to the culture of consumers and corporate management in this country. This is also an area where more advanced techniques and contributions can be expected from research and development using Japanese approaches. In addition to practical benefits, promotion of public research and publication of the results can be expected to improve the current situation in which research results are not made public, and thus will also be useful in promoting theoretical research.

3-2 Challenges toward advanced logistics and the role of OR

(1) Response to wider area, more complex supply chain networks

(a) Optimization of facility location and transportation route in large-scale logistics networks

One issue with particular attention in recent logistics is the problem of optimization of the network structure as a whole, as these networks are spreading and also more complex.[10,11]

A transportation network in logistics comprises connecting nodes such as resource suppliers, production plants, warehouses, and the final consumer, and the transportation links joining those nodes. The mathematical model of entire network could be an extremely large-scale network model, often having equations and variables more than 10,000. A number of reports have presented examples in which it was possible to realize nearly 30% reduction of operation and transportation cost by optimal rationalization of the site location arrangement and selection, and transportation network. In particular, reduction of transportation costs, which accounts for the main part of cost reduction, makes a direct contribution to reducing transportation distance, and therefore also contributes to reducing emission of greenhouse gases.

Because problems of optimum routes and site locations in large-scale, multi-stage networks treat variables which must be expressed by numerical values, i.e., the number of site, number of cars or transportation facilities, and combinations of delivery routes and sites, these are fundamentally optimization computation by using extremely large-scale integer programming models (several 10,000 to 1 million variables or more). Until recently, this type of problem could only be handled by research institutions with very limited computational capabilities. In recent years, with progress in computational algorithms and higher speed and larger capacity of computer hardware, it has now become possible to solve these problems at a practical speed using a general personal computer. As a result, it has become relatively easy to perform optimal design and planning for large-scale, wide area supply chains.

Figure 4 shows an example of the scale of that type of computational model. An optimization model for route selection which includes combinations of all the alternatives, such as the number of nodes, product models, transportation method, and the like, will be enormous. In Japan, application of mathematical models for rationalization of this type of supply chain network had attracted a little attention in the past due to the lack of knowledge of and interest in mathematical optimization. However, due to the increased transportation costs caused by the recent jump in fuel prices, ongoing closure/consolidation of bases in response to corporate mergers and other factors, etc., application is continuing to advance in a wide range of areas in Japan. Figure 5 shows an example of optimization planning for distribution network in North America for a consumer electronics maker. [12] In Europe and the United States, where transportation network is spread in broad geographical fields, many variations of research including multi-modal transportation are being carried out in both the theoretical and practical aspects by private corporations, universities and other research institutions.

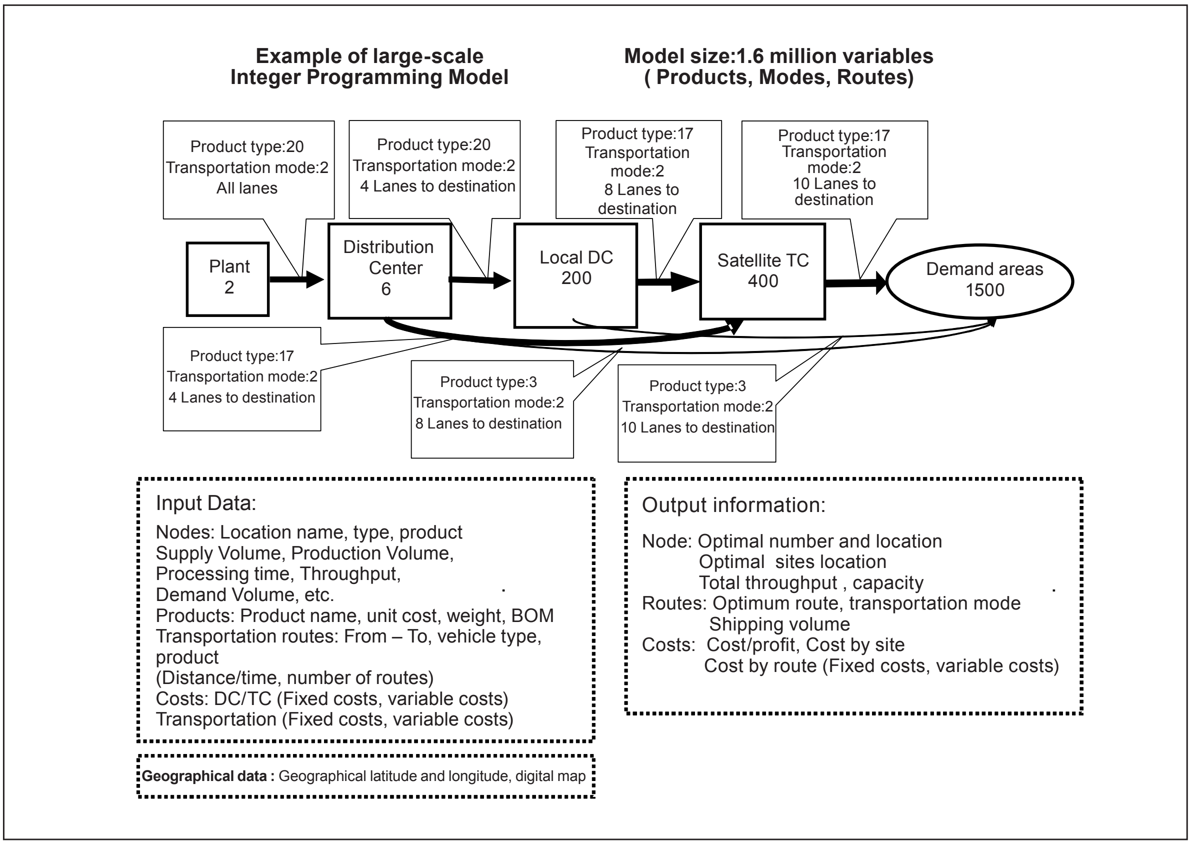
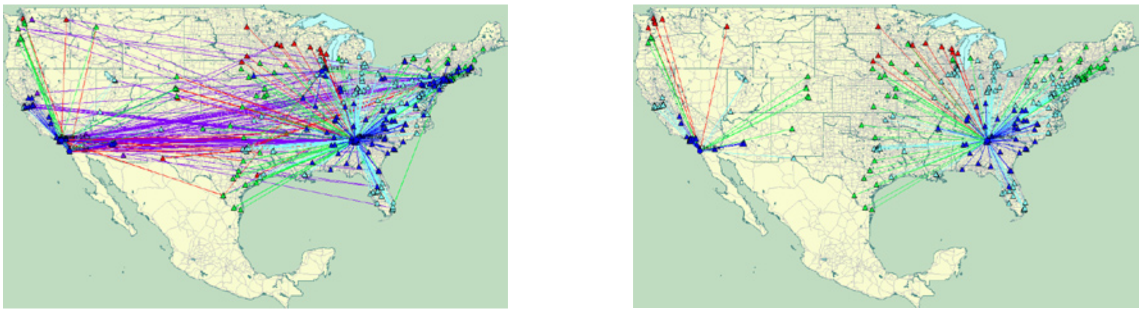


Figure4 : Example of large-scale logistics network model

Prepared by the STFC based on materials of Frameworx Inc.



Original delivery routes before optimization

Optimization result with 2 distribution centers
(Total distance and delivery time were shortened by more than 30%)

Figure5 : Optimization results of North American distribution network of a consumer electronics maker.

Prepared by the STFC based on reference[12]

In particular, in the European nations, for example, the Netherlands and Belgium, government policy promotion measures has been studied by using mathematical models and proposed,[13-15] and logistics centers have been developed targeting to service American and Japanese companies, with the country's port or airport as the point of origin, and a multi-modal integrated transportation network combining sea transportation (short sea shipping by Ro-Ro ship), truck, railway, and river transportation for the entire EU region.

In Japan, the opening of the FY2008 "White Paper on Monodzukuri" mentioned the importance of supply chains and the necessity of promotion of strategic logistics networks. In this aspect, cooperation in logistics with the Asian countries and Russia will be particularly important for Japan in the future. For example, that report states that several companies are already started using the Trans-Siberian Railway to cut transportation time from Japan to Europe by half, from more than 40 days to around 20 days, and the government has also announced that it will support modernization under the "Eurasian Industrial Investment Bridge" concept.[16] While hardware such as measures for vibration of railways and transportation facilities will be necessary in the construction and operation of an Asia-wide transportation network, what will be particularly important in the future will be rational operation of the entire network of transportation routes, combining land and sea routes. Therefore, it is desirable to carry out a strategic research, including cooperation with the other East Asian nations, and to implement construction and improvement of port and harbor facilities and inland terminal warehouses in a policy-oriented manner, based on horizontal cooperation among the ministries and agencies concerned. In the future modernization of logistics in Asia, Japan must take the lead in optimization research on the international logistics network cooperating other neighboring nations.[17]

(b) Inventory reduction by optimization of safety stocks

In wide area networks, placement of large quantities of inventories close to the final demand is not the optimal solution, economically speaking, for responding to fluctuations in final demand and shortening lead time in supplying customers. Where in the network to hold the optimum safety stock, and what amount to hold, considering supply and transportation lead time, are major problems from the viewpoints of effective utilization of resources and economic optimality. Obtaining practical solutions had been considered a difficult problem, but this is now approaching a solution by recently-developed techniques using dynamic programming and complex system simulation technology, and others.[10,18] There are examples in which the cost reduction achieved by this type of optimization reaches 30%. Likewise, in order to respond to globalization, which was mentioned previously, a large economic effect by further development of optimization technology is also expected in the future. In particular, in manufacturing industries which are engaged in international market development, the profit from optimization of the inventory location and quantity of service parts, based on the relationship between the service level and inventory costs, is large. A leading northern European furniture maker[19] and a European tire maker, PC printer makers, automobile makers, and others who are expanding internationally are actively engaged in research. Theoretically, optimization of site locations from the viewpoint of transportation costs and inventory handling in network should essentially be performed simultaneously; however, no solution method which enables simultaneous optimization of these two problems has been discovered as of the present. This is a field where further research is expected.

(c) Modal shifting and multi-modal transportation

Accompanying the recent globalization of production and market, optimization programming of multi-modal, internationally integrated transportation combining land (truck, container, rail), sea (container ships and trailer ships), and air has become necessary. Because this is accompanied by greater complexity in transportation routes and the difficulty of time planning, here, new mathematical method is expected for rational selection of transportation routes and operational planning. Furthermore, as mentioned previously, in the establishment of plans for large geographical areas, and particularly the Asian region and transportation between Asia and Europe, research on multi-modal transportation will be indispensable.

Similar problems have arisen in CO_2 reduction plans by modal shift in Japan. Here, planning which combines trunk-line transportation and local transportation ("last one mile") has become necessary.[20-23] Recently, examples have been published in which a CO_2 reduction of 20% was realized by large-scale milk run-type collection/delivery to an electronic part assembly plant, and trunk-line transportation to complete-product demand areas and combined delivery to final customers implementing a large-scale vehicle allocation and control system.[24-26]

It has become difficult for research institutions such as universities to do research in the field represented by the above case due to the difficulty of obtaining practical data in Japan. In Europe and the United States, it is possible to obtain transportation cost tariffs openly. Moreover, as mentioned previously, several alternative means of transportation exist for the geographically extensive networks (truck, trailer, rail, river transportation, air routes). Therefore, research on this area is being carried from a variety of directions. In Japan, joint research with private companies is of course being carried out for effective utilization of local ports and harbors and activation of regional industrial clusters, but more active research on optimization of transportation extending beyond administrative divisions is also desired.

(2) Issues in which development of new methodologies for model construction and optimization are expected

The following are the topics important in the logistics of any company. However, further research on solution methods, conducted through industry-university collaboration, is expected. If the development of new techniques can be realized by cooperation between practical businesspeople and Japan's outstanding researchers in the mathematical sciences, this will have the potential to contribute to logistics and OR at the world level, although there are still problems which are left to individual companies in practical responses.

(a) Dynamic delivery planning optimization for agile response to demand

In the future, high expectations will be placed on the development of new mathematical solution techniques for realizing advanced production and transportation systems which are capable of responding quickly to changing demand. Technologies for real-time rescheduling and vehicle assignment and route planning by using real-time data collection through GPS and RFID are expected by breakthroughs such as practical application of the aforementioned large-scale optimization algorithms, etc.

Rationalization of truck dispatching using tools involving mathematical algorithms is continuing to gain acceptance in Japan. However, because energy saving and cost reduction by alleviation of urban traffic and improvement of the current 50% truck load rate will contribute directly to reduction of greenhouse gases, more sophisticated vehicle allocation planning systems and their dissemination are desired. Wide implementation of detailed operation plans by these technologies, including higher efficiency by joint loading and joint delivery of cargos, reduction of operating costs by proper time windows for deliveries, combined collection and delivery, etc. will also contribute to promoting green logistics, which will be discussed later in this paper.

(b) Procurement planning for risk management and economic optimality

Accompanying globalization and open sourcing in the procurement of raw materials and parts, solutions using combinatorial theory can be expected in responding to risks such as natural disasters and terrorism, procurement planning with stable supply and economy, and optimum selection of sources involving complex factors.

In order to secure alternate means of transportation in response to traffic disruptions due to natural disasters such as earthquakes, etc., the necessary public financing must be decided rationally. Simulation of social costs by mathematical study is considered useful in this kind of decision making.

(c) Concurrent design of products and supply chain

Recently, one area where research is also continuing to advance in other countries is a methodology of performing design of the supply chain simultaneously and in parallel with product design, in which the product design itself is changed considering optimum procurement and product delivery. In one example from Japan, a copying machine maker succeeded in reducing costs by broadly shortening delivery time and reducing stocks, by restudying where the location of final product assembly should be located in the supply chain and performing design for modularization of parts to enable production of final products easily at intermediate locations in response to market requirement, however this practice was not led from theoretical optimization. In generalizing this kind of design technique, including part procurement routes, research and development of new mathematical techniques is required, including simulation techniques for complex systems, etc.

Supply chain optimization, including the product design, will have a positive influence in the implementation of carbon footprint, which will be applied in the near future. The carbon footprint of products will be shown on the product package, etc. Under this concept, the greenhouse gases emitted over the entire life cycle of the product, from raw materials to production, sale, distribution and consumption, are expressed in terms of the amount of CO_2 emissions. This is being promoted actively in the United Kingdom, and study in Japan has also begun. By encouraging consumers to select products with low environmental impacts, manufacturers can be encouraged to produce products with lower impacts.[27] In addition to generation of greenhouse gases by energy sources in the production plant, environmental loads can also increase as a result of transportation, depending on the site location of the plant.

(d) Research on mathematical solution measures for new transportation methods and their effective utilization

In the future, it is thought that the development of new means of transportation will be promoted with the aim of reducing energy costs and environmental impacts. Innovations in the hardware aspect are continuing to be realized. These include international trailer transportation using Ro-Ro ships, responding to the needs of medium- and short-distance marine transportation. Ro-Ro is an abbreviation for Roll-on/Roll-off ship, and is a type of cargo vessel with a structure that enables loading and unloading of vehicles such as trailers under their own power. This method is more suitable than the container method for medium- and short-distance transportation. Other examples include practical application of multi-modal transportation using new rail containers and dedicated trailers, which have already been implemented by an automobile maker, transportation of 40 foot marine containers by rail and consolidation of cargos and arrangement of transshipment centers for its effective utilization, etc. New optimization systems for operation planning suited to these innovations are demanded. In addition to this, in order to realize circulatory-type logistics for resource saving, further research must be carried out on international container management, pallet management, route planning techniques for circulatory transportation, and similar topics.

(e) Design of business work flow structure in supply chains and research for optimization

Research on application of a standardized process operation reference model (SCOR model)[29] and business process modeling (IDEF, etc.) for optimization of the structure and work flow of supply chains combining multiple companies and different business entities is increasingly necessary. In supply chain rationalization in Japan, which tends to begin and end with only a response to individual issues, there is little familiarity with top-down type model structures and design concepts that intend this kind of total optimality from the outset. Recently, these have at last begun to attract attention. Further research for future supply chain rationalization from a total viewpoint is demanded. On the other hand, methodologies such as SCOR are fundamentally premised on top-down organizational management. Accordingly, in order to demonstrate effectiveness in Japan's bottom-up type decision function, unique theories for modeling and implementation which are not simply copies of those in Europe and the United States must be researched.

(f) Research on supply chain structures in cooperation with social science approach

Supply chain networks comprise numerous companies in the same or different industries (and in cases, companies with different nationalities). The decision-making in each company must be conscious of the existence of other decision-making units (other companies). However, conventional theory and management solutions are materialized on the precondition of a single decision-making unit. For scientific treatment of strategic decision-making premised on this type of interaction, it is necessary to borrow the assistance of game theory and microeconomics, or agent model approach, etc.[29] In order to analyze the behavior of a supply chain network, which has a complex structure, including environmental problems, and measure and improve their efficiency, interdisciplinary cooperative work between research by scientific and mathematical approaches and research by social science approaches is indispensable. In other countries, research on supply chain and logistics problems by this kind of cooperative work are made widely, and a number of papers have been published in management science journals. It is thought that researching the ideal form of management from an interdisciplinary standpoint will not be only useful in corporate decision-making, but will also provide valuable knowledge for making industrial policy in Japan.

3-3 Role of OR in promotion of green logistics

With the start of the 1st commitment period under the Kyoto Protocol, which is from 2008 to 2012, Japan is targeting a 6% reduction in emissions of greenhouse gases during this period from the baseline years (fiscal 1990 for CO_2, CH_3, and N_2O and fiscal 1995 for the 3 gases classified as chlorofluorocarbon-replacing material, etc.). However, in actuality, Japan's emissions of greenhouse gases in fiscal 2006 were 1.34 billion tons (CO_2 conversion), which was an increase of 6.2% against the baseline year.

The main cause of this increase was a large increase of 12% in fiscal 2006 against the baseline year in CO_2 emissions originating from fossil fuels, which account for approximately 90% of Japan's emissions of greenhouse gases. Emissions from the transportation sector, which is responsible for approximately 20% of CO_2 emissions originating from fossil fuels, increased by about 20% from fiscal 1990.

In addition to these circumstances, transportation costs have also increased due to the recent sharp rise in the price of fuel oil. Against this background, energy conservation in the logistics sector has become extremely important for protecting the foundations of Japanese industry.

As touched on in the connection with the application of OR to various problems discussed in Chapter 3, rationalization of logistics can make many direct contributions to the realization of green logistics. However, distinctive problems or challenges also exist in green logistics.

In application of OR to green logistics, one topic which particularly requires research is a technique and model structure for simultaneous optimization of multiple objective functions, i.e., energy efficiency, greenhouse gas emissions, cost, and the like. In optimization of mathematical models, research on the establishment of solutions which simultaneously satisfy multiple objective functions and so-called multi-objective programming is necessary. Several proposals have been advanced as solution methods for multi-objective function models for green logistics. These proposals can be broadly classified into (1) methods in which multiple objective functions are solved individually, assigned certain weights, and summarized in a single function, which is then either minimized (total environmental impacts + cost, etc.) or maximized (effect of countermeasures), (2)

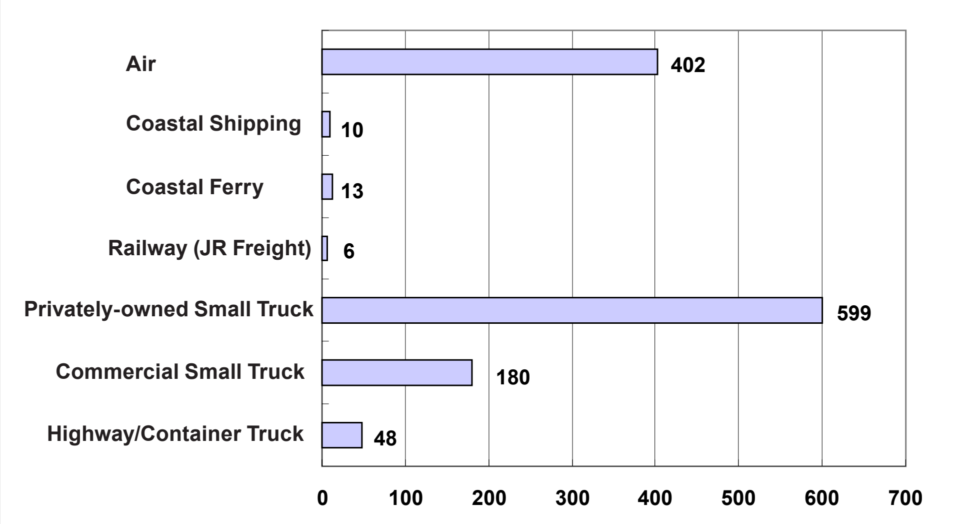


Figure6 : CO_2 emissions by means of transportation (g/ton-km)

Prepared by the STFC based on reference[30]

methods in which minimization or maximization of a certain objective function is solved using the target values of other objective functions as constraints, and (3) methods in which the point of convergence of the values of multiple objective functions is obtained using, for example, Pareto optimization, etc. However, none of these proposals has become a definitive method. Therefore, research on both methods of modeling actual problems and mathematical solution methods is expected.[20]

Although already touched on in Chapter 3, one other major challenge is research in connection with modal shift and multi-modal transportation. Emissions of CO_2 differ greatly depending on the means of transportation, as shown in Figure 6. Accordingly, research on means of transportation will demonstrate effectiveness in the prevention of global warming. Among concrete countermeasures, an example in which a CO_2 reduction of 20% was achieved by appropriate vehicle assignment and deliver planning was mentioned previously as one method that has already begun to be implemented. Modal shift is expected to have an even larger effect. Already, an example in which a CO_2 reduction of nearly 80% was realized by switching to rail transport for trunk-line transportation and future reduction plans by joint use of short sea shipping have been reported.[25] As also noted previously, it is considered that implementation of the concept of carbon footprint and its importance will become increasingly great.

In Japan, however, until now study has been limited to the range of individual companies, and almost no research has been done by OR on inter-company problems or toward national policy. In Europe, much research is being done on the EU as a whole, particularly in universities, and proposals are being made. In promoting rationalization of logistics as a national policy, a cooperative system which extends beyond the boundaries not only of companies, but also those of government ministries and agencies and local governments is indispensable.

Universities and public research institutes should play a large role in drafting composite and comprehensive plans, not limited to structuring individual infrastructure such as port and harbor or road construction and improvement, but also in the effective distribution of cargo collection and delivery bases and improvement of their functions, combination of trunk-line transportation, including railways, and deliveries to individual customers, which is called "last one mile," etc., as well as in the development of models for these problems, research on optimization algorithms, and the like. Prioritized financial support policies for this type of research may also be effective.

As mentioned earlier, it is also necessary to study modal selection, including land, sea, and air, in research in connection with construction of a transportation network which includes the entire Asian region and Russia, and policies for reducing international environmental impacts accompanying the realization of such a network.

3-4 Expectations on service science research towards advanced logistics

In the final report of the United States' Council of

Competitiveness, which is entitled “Innovate America: Thriving in a World of Challenge and Change” (April 12, 2004; generally abbreviated as the “Palmisano Report”),[31] “service science” was introduced as a new academic field with the potential to induce innovation. Service science is important as one direction for the development of science and technology responding to new industrial structures. Needless to say, it is considered possible to obtain substantial benefits by advances in service science in the logistics industry, which occupies a large position in the service industry.

The Palmisano Report also pointed out the following with regard to the relationship between service science and OR: “There is no field in which a new interdisciplinary approach is so clearly necessary as in the new field of ‘service science’. Service science is a fusion of existing fields, including computer science, operations research (OR), production engineering, mathematics, management science, decision science, the social sciences, forensic sciences, and others. This causes reform in corporate activities as a whole, and encourages innovation in the region where the specialized knowledge of technology intersects with business.”

As good examples of improvement of service productivity by OR, bank ATM windows and JR railway ticket counters can be mentioned. By changing the form of queuing from the previous queuing at each window to a forked form of queuing, waiting time as a whole was shortened and the service rate per unit of time was increased. This change also had a positive effect on customer psychology. This is an example of application of queuing theory, which is one typical OR technique. Although popularization in Japan was comparatively recent, it is generally said that a demonstration experiment video by (then) Prof. Morimura of Tokyo Institute of Technology on the 1991 NHK television program “Try and Try” had an very large influence on its rapid acceptance.[32] Queuing theory is used in the design of the number of service windows and their operation, and in addition to ticket counters, has also been applied to the design of toll booths on expressways, the number of passport inspection gates in airports, etc.

One of the purposes of service science is improvement of productivity, reduction of costs, and improvement of quality by application of engineering techniques to services. In other words, it is a science which researches a total design by quantifying services, modularizing and standardizing service solutions, and combining modules, and through these practices, applying engineering techniques to the service industry and thereby improving service productivity.

Logistics is considered to be an area where important effects can be expected by promoting interdisciplinary research by the service science approach. In particular, in the aspect of service quality, quantitative concepts such as KPI (Key Performance Indicator), metrics, benchmarking, and similar techniques applied to service quality have already achieved penetration. This field also has conditions which facilitate study of objects of research, in that data collection is easy, the relationship between the service provider and beneficiary (customer) can be defined relatively clearly, etc.

For example, one quality-related concept in logistics is “Perfect Order Fulfillment Rate.” Although several different definitions of this concept exist, for instance, in the definition in the above-mentioned SCOR, this is defined as the numerical value obtained by multiplying the four percentages of the quantitative completion rate, on-time delivery rate, documentation completeness, and non-damage rate.[28] This has become one index of quality assurance for logistics contractors in Europe and the United States. However, in Japan, contracts which attach importance to numerical values other than cost are still rare. In the future, it is thought that this may be suitable material for research on the relationship between quality and cost or productivity.

On the other hand, in research on service science, it is considered necessary to avoid over-reliance on a reductionism methodology that reduces the object to its basic elements and understands it in numerical values that can be quantified physically. In performing analyses of service quality and customer satisfaction and preparing the optimum design, techniques in the field called decision science within the larger discipline of OR could be very effective. Examples include AHP[34] (Analytical Hierarchy Process; recently used in narrowing the field of candidates for relocation of the capital) for assessing the value of non-quantitative factors, conjoint analysis (technique used in analysis in marketing for product design, etc.), DEA[35] (Data Envelopment Analysis; in actual examples, has been used in analysis of public service institutions such as libraries and hospitals, etc.) for evaluating the efficiency of organizations while simultaneously handling multiple inputs and outputs, and others.

In service science, areas of research where Japan can particularly contribute are research in connection with evaluations of qualitative/sensible quality, which tends to be slighted in the Western European approach, and research based on holistic ideas, which consider the whole and its parts simultaneously and are a distinctive quality of the Japanese people's way of understanding the world

Japan's unique, and it can be said, excessive insistence on quality can also be seen in the field of logistics. While this also has an aspect of increasing social costs, at the same time, its effect in bringing about a more pleasant life for the country's citizens must not be overlooked. If the Japanese approach can compensate for the weaknesses of other evaluation standards that insist on quantifiable numerical values by promoting interdisciplinary and boundary-region research, this will be important as part of this country's contribution to the development of service science. In the past, in quality control of industrial products, Japan demonstrated that it is possible to satisfy both quality improvement and cost reduction simultaneously, which had been considered mutually contradictory until that time. Similar examples can be seen in logistics. For instance, in deliveries of goods to convenience stores, vehicle allocation planning by OR and transfer-type delivery centers have been used, and delivery schedules by detailed temperature range have been combined in dedicated vehicles. When the first convenience stores were opened in 1974 in Tokyo, the number of deliveries was 70 vehicles per store per day and 42 two years later. As a result of these efforts, the number of deliveries was reduced to 15 in 1987 and to only 9 in 2005, while the freshness of boxed lunches and bread has actually improved. This is an example in which both service and efficiency issues were successfully solved.[36] From this viewpoint, it is thought that Japan can contribute to service science as a whole if it can analyze this country's strengths and weaknesses in logistics and, with this as a reference point, conduct research on quality in logistics using an interdisciplinary approach.

4 Conclusions and recommendations

Supply chains play a critical role as the foundation for industry, but are now facing major turning points. This report has described the effectiveness of support for rational planning and operation of supply chains by optimization methods and simulations using OR techniques, and in particular, the challenges which will require research and development efforts in the future.

In particular, Figure 7 summarizes five key themes among problems requiring solutions, as described in Chapter 3, and the corresponding R&D themes for OR techniques. As mentioned previously, in order to respond to the challenges of greater complexity, large geographic extent, and internationalization which today's logistics confronts, and to solve future problems when they arise, research must be promoted on issues having a strategic viewpoint, as shown on the left in Figure 7. It is also necessary to simultaneously promote research and development of more advanced OR techniques which are capable of modeling complex realities, as shown on the right, and providing practical solutions.

In addition to promoting research on these key challenges, when promoting developmental research on advanced logistics and OR techniques for this purpose in the future, the policy responses outlined below will also be necessary.

(1) Logistics as an engineering subject and development of human resources

In comparison with Europe and the United States, rationalization and optimization of logistics by OR techniques has not been well promoted in Japan in the past. One reason for this is that logistics has been understood as basically an engineering subject in Europe and the U.S. As a result, research has been actively promoted in science and technology-related educational and research institutions, and independent departments or faculties were established in higher education from an early date. In contrast, in Japan, there is a strong tendency to understand logistics as a business in commercial science and as an ancillary to sales and marketing. For this reason, its position has not been well established; either in companies or in the science and engineering community.[37] In recent years, science and engineering universities have become central to the promotion of advanced logistics in Europe, the U.S., and some Asian countries. Likewise, it is desirable to create a logistics research promotion system which prioritizes science and engineering in Japan. In Europe and the U.S., training

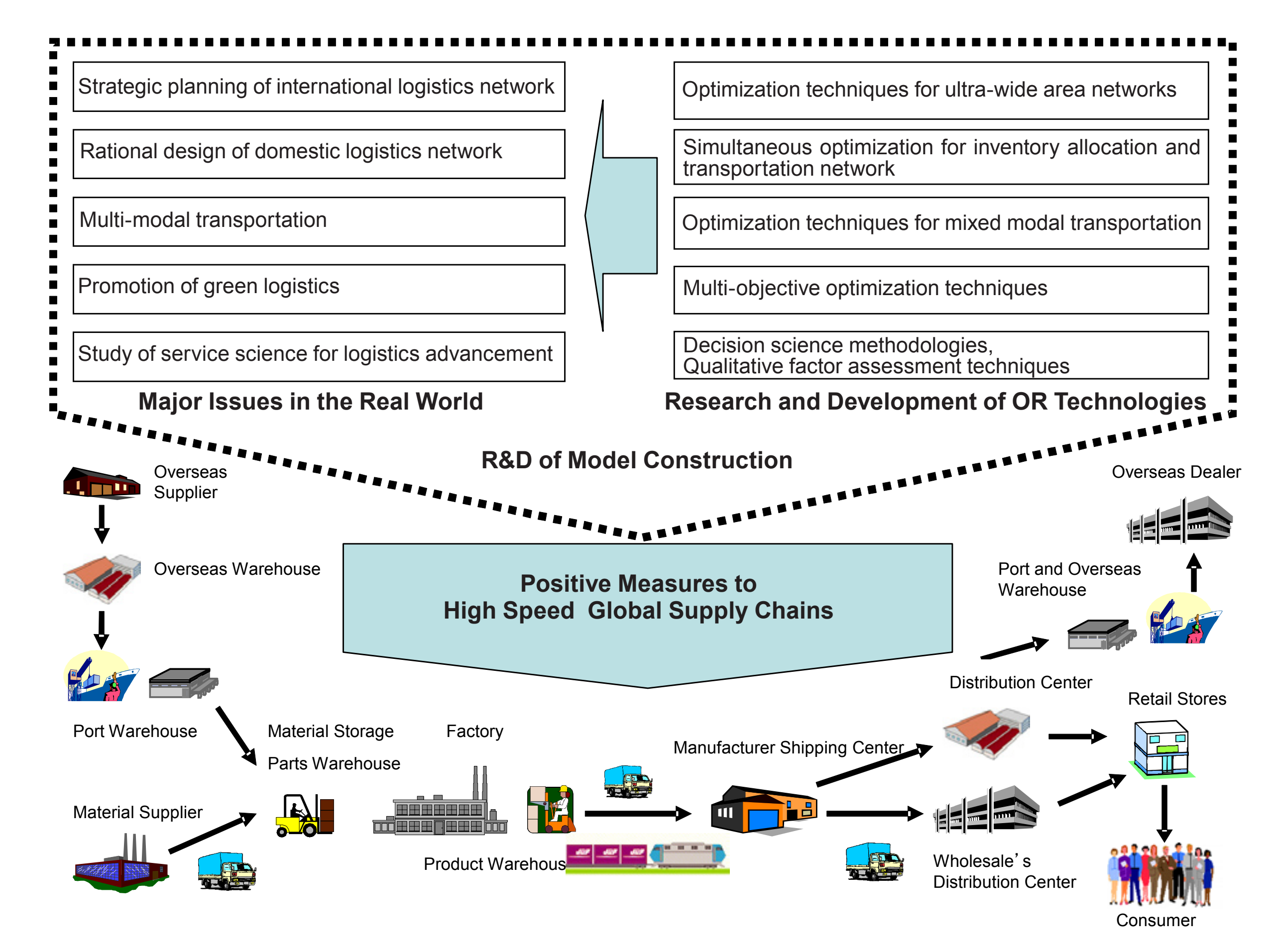


Figure7 : Real problems requiring solution R&D on model construction methods

Prepared by the STFC

of specialists with advanced capabilities, for example, who can make full use of OR techniques, has been mentioned in policy recommendations in connection with supply chains, and joint research to establish practical academic system and curriculum to educate SCM specialist has begun in industry, universities, and government agencies.[38,39] Universities in the Asian countries have also embarked on training of specialists in SCM and logistics specialists with advanced capabilities by promoting cooperation with European and American universities.[40-42] In order to realize more advanced logistics in Japan, training of human resources on the same level as those in other countries is an urgent matter for promoting research and development, and does not permit further delay. By promoting logistics education and research in institutions of higher education, Japan can contribute to improvement of the international level in Asia in this area, and can become a promoter of international cooperation. This is considered one important policy issue for the future.

(2) Recognition of logistics, SCM, and OR as research fields

At present, the items of supply chain management and logistics are not included in the systems, fields, sub-divisions, or detailed items of the Grant-in-Aid for Scientific Research (Kakenhi) program of the Japan Society for the Promotion of Science (JSPS). In order to promote research and development in these fields, it is considered necessary to recognize these as research fields by adding them to the JSPS program. These items are also not included in the classification of technical fields by the Japan Science and Technology Agency (JST), and it is desirable that they be added to this classification. Furthermore, the items of management science, OR, and management engineering, which are considered important areas for promoting research in Europe and the United States, are not independently included in the technical fields of both programs. It is desirable that addition of these items also be realized quickly. A number of academic societies which already have histories and scales exist. Hence, if this type of action can be taken, it will make a large contribution to activating research and development in the related academic societies.

(3) Interdisciplinary and interagency research system

If the development of OR to green logistics and services science is considered, promotion of interdisciplinary research combining science and engineering related fields, fields of social science such as economics, and the human sciences is demanded. In this kind of boundary-area research and development, there are latent possibilities for Japan to contribute to the development of OR at the world level by researching the strengths and weaknesses of the Japanese social system and realizing problem-solving from a more total viewpoint, without being bound by the reductionism approaches favored in Europe and the United States. A research support system for realizing these possibilities is required.

Acknowledgements

In writing this paper, the author interviewed more than 30 persons including university researchers and businesspeople. I wish to express my profound gratitude to all those concerned for the information and materials provided, which brought invaluable reference for this work. In particular, I wish to acknowledge the valuable suggestions received through discussions with the members of the supply chain-related research chapter of Operations Research Society of Japan, Japan Industrial Management Association, Japan Logistics Society, CSCMP Japan Roundtable, and Japan Chapter of Supply Chain Council.

References

[1] Ministry of Economy, Trade and Industry, Ministry of Health, Welfare and Labor, Ministry of Education, Culture, Sports, Science and Technology, “White Paper on Monodzukuri 2008 (Promotion Policy for Basic Technologies in Monodzukuri in FY2007).” (2008). (Japanese)

[2] Council of Supply Chain Management Professionals : http://cscmp.org/default.asp

[3] D. M. Lambert, J.R. Stock, “Strategic Logistics Management,” Mcgraw Hill/Irwin (2000).

[4] Donald J. Bowersox, et al. (trans. by Eji Abo), “Supply Chain Logistics,” Asakura Publishing Co., Ltd. (2004). (Japanese)

[5] Mitsuru Kuroda, ed.,“Supply Chain Management : Theory and Reality of Intercompany Cooperation,” Asakura Publishing Co., Ltd. (2004). (Japanese)

[6] Japan Institute of Logistics Systems, “Report on Survey of Logistics Costs FY2007,” (2008). (Japanese)

[7] Japan Productivity Center for Socio-Economic Development,“International Comparison of Labor Productivity (2006).” (Japanese)

[8] Takao Enkawa, “Strengths of Japan’s Site Capabilities and Weaknesses of Management Seen from an International Comparison by SCM Performance Score Card,” National Institute of Science and Technology Policy, Materials of an internal lecture (2008). (Japanese)

[9] Hiroshi Konno, “Useful Linear Equation – 50 Years of the Integer Programming ‘Capricious Princess,’” Nippon-Hyoron-sha Co., Ltd. (2006). (Japanese)

[10] David Simchi-Levi, et al. (trans. supervised by Mikio Kubo), “Designing and Managing the Supply Chain – Concepts, Strategies, and Examples,” Asakura Publishing Co., Ltd. (2006). (Japanese)

[11] Mikio Kubo, “Introduction to Supply Chain Optimization,” Asakura Publishing Co., Ltd. (2004). (Japanese)

[12] Kazuyuki Izutsu,“Basic Concepts and Functional Requirements of International Logistics,” Report of the Supply Chain Workshop, Operations Research Society of Japan, (2005). (Japanese)

[13] “Supply Chain 2020 Project Working Paper, A Review of the Leading Opinions on the Future of Supply Chains,” Dec. 2004.

[14] Allan Woodburn, “An Investigation of Container Train Service Provision and Load Factors In Great Britain,” University of Westminster (2006).

[15] Toshihisa Fujiwara, "Survey of Total Land, Sea, and Air Logistics in Belgium – As an Advanced Example for East Asia/Northern Kyushu – ," Preprints of the 25th National Conference of the Japan Logistics Society (2008). (Japanese)

[16] Japan Association for Trade with Russia and NIS, Materials of the 16th RBC International Business Conference, Noriaki Kojima, Director, Russia Office, Europe-Middle East-Africa Division, Economic and Industrial Policy Bureau, Ministry of Economy, Trade and Industry (METI), "The Japanese-Russian Economic Relationship and the Railway Field" : http://www.rotobo.or.jp/activities/rbc/rbc9_2.pdf (Japanese)

[17] Masaharu Iwama, "Globalization of Asia Considered from the Viewpoint of Logistics," Shizuoka Academic Press (2008). (Japanese)

[18] David Simchi-Levi, "A New Approach for Inventory Planning," Presentation, CLM2004 (2004).

[19] J. Shapiro, T. Dudas, "Building the Optimal Logistics & Distribution Network Strategy," Presentation, CLM2004 (2004).

[20] Irina Harris, Mohamed Naim and Dr. Christine Mumford," A Review of Infrastructure Modeling for Green Logistics," Cardiff University (2007).

[21] J. Quariguasi Frota Neto, J.M. Bloemhof-Ruwaard, J.A.E.E. van Nunen and H.W.G.M. van Heck, "Designing and Evaluating Sustainable Logistics Networks," Erasmus Research Institute of Management (ERIM) (2006).

[22] A. Sbihi, R.W. Eglese, "The Relationship between Vehicle Routing & Scheduling and Green Logistics- , A Literature Survey," Lancaster University Management School (2007).

[23] Julie Paquett, "The Supply Chain Response to Environmental Pressures," MIT (2005).

[24] Green Logistics Partnership Conference, "Guide to Green Logistics," Commerce and Information Policy Bureau, METI (2008). (Japanese)

[25] Japan Institute of Logistics Systems, "2nd Period Conference on Green Logistics in Japan, Report on Activities of the Green Logistics Study Group FY2007," Japan Institute of Logistics Systems (2008). (Japanese)

[26] Yuji Yano, Katsuhiko Hayashi, "Typology of Efforts by Japanese Companies to Address Logistics-related Environmental Issues," Ryutsu Keizai University (2007)

[27] Hiroki Kudo (Institute of Energy Economics, Japan), "Recent Trends and Future Outlook for Standardization of Greenhouse Gas Management," Japan Environmental Management Association for Industry (2008). (Japanese)

[28] Supply Chain Council, "Supply Chain Operation Reference Model V.9.0" (2008).

[29] M. Nagarajan, G. Sosic, "Game-theoric Analysis of Cooperation Among Supply Chain Agents: Review and Extensions," European Journal of Operations Research (2006).

[30] Japan Federation of Freight Industries "Logistics Data Book" (2007). (Japanese)

[31] National Innovation Initiative and Summit and Report, "Innovate America-Thriving in a World of Challenge and Change," Council of Competitiveness (2005).

[32] Hidenori Morimura et al., "Try & Try: Smart Waiting and Making Wait," NHK Archives (January 29, 1991). (Japanese)

[33] Seiichi Fujita et al., "Actuality of the Japanese Logistics Site and the Quest for Best Practice," Material Flow (August 2008). (Japanese)

[34] Eizo Kinoshita and Eiji Ono eds., "AHP and Conjoint Analysis," Gendai-Sugakusha (2004). (Japanese)

[35] Kaoru Tone, "Measurement and Improvement of Management Efficiency," Union of Japanese Scientists and Engineers (1993). (Japanese)

[36] Yoh Tanaka, "Seven-Eleven – Secrets of the Winner," Nikkei Publishing, Inc. (2006). (Japanese)

[37] Takao Enkawa, Ryuichi Ichikawa, "Managers Born from Logisticians," Management and Logistics Vol. 1 (2008). (Japanese)

[38] Jake Barr John Dischinger, "The Emerging Need for Supply Chain Talent: Working to fill the gap . . . , " Supply-Chain World 2008, Supply Chain Council (2008).

[39] D. Aquino and L. Draper, "Supply Chain Talent : State of the Discipline," AMR Research

[40] National University of Singapore : http://www.tliap.nus.edu.sg/

[41] The Hong Kong University of Science and Technology : http://www.ielm.ust.hk/

[42] Supply Chain & Logistics Institute : http://www.tli.gatech.edu/research/china/
"TLI-Asia Pacific Program Sets Goals for Next Five Years" :
http://www.tli.gatech.edu/news-events/release.php?id=188

Profile

Eizo TAKAI
Affiliated Fellow,NISTEP
Chief Technical Advisor, Frameworx Inc.
http://www.frame-wx.com

Mr. Takai holds a Master's Degree in Management Science and Operations Research from Columbia University. More than thirty years of experience in the field of management science and supply chain management in the real industry, he turned into the academic world 15 years ago as a professor of Shizuoka University. He is an active member of many professional societies such as Japan Operations Research Society (Fellow, former vice president) , Supply Chain Council Japan (Board member), Japan Industrial Management Association (Chief editor of communication) , Japan Logistics Society (Board member) , CSCMP, INFORMS, etc.

(Original Japanese version: published in October 2008)

About SCIENCE AND TECHNOLOGY FORESIGHT CENTER

It is essential to enhance survey functions that underpin policy formulation in order for the science and technology administrative organiztions, with MEXT and other ministries under the general supervision of the Council for Science and Technology Policy, Cabinet office (CSTP), to develop strategic science and technology policy.

NISTEP has established the Science and Technology Foresight Center (STFC) with the aim to strengthen survey functions about trends of important science and technology field. The mission is to provied timely and detailed information about the latest science and technology trends both in Japan and overseas, comprehensive analysis of these trends, and reliable predictions of future science and technology directions to policy makers.

Beneath the Director are six units, each of which conducts surveys of trends in their respective science and technology fields. STFC conducts surveys and analyses from a broad range of perspectives, including the future outlook for society.

The research results will form a basic reference database for MEXT, CSTP, and other ministries. STFC makes them widely available to private companies, organizations outside the administrative departments, mass media, etc. on NISTEP website.

The following are major activities:

1. Collection and analysis of information on science and technology trends through expert network

— STFC builds an information network linking about 2000 experts of various science and technology fields in the industrial, academic and government sectors. They are in the front line or have advanced knowledge in their fields.

— Through the networks, STFC collects information in various science and technology fields via the Internet, analyzes trends both in Japan and overseas, identifies important R&D activities, and prospects the future directions. STFC also collects information on its own terms from vast resources.

— Collected information is regularly reported to MEXT and CSTP. Furthermore, STFC compiles the chief points of this information as topics for “Science and Technology Trends” (monthly report).

2. Reserch into trends in major science and technology fields

— Targeting the vital subjects for science and technology progress, STFC analyzes its trends deeply, and helps administrative departments formulate science and technology policies.

— The research results are published as articles for "Science Technology Trends" (monthly report).

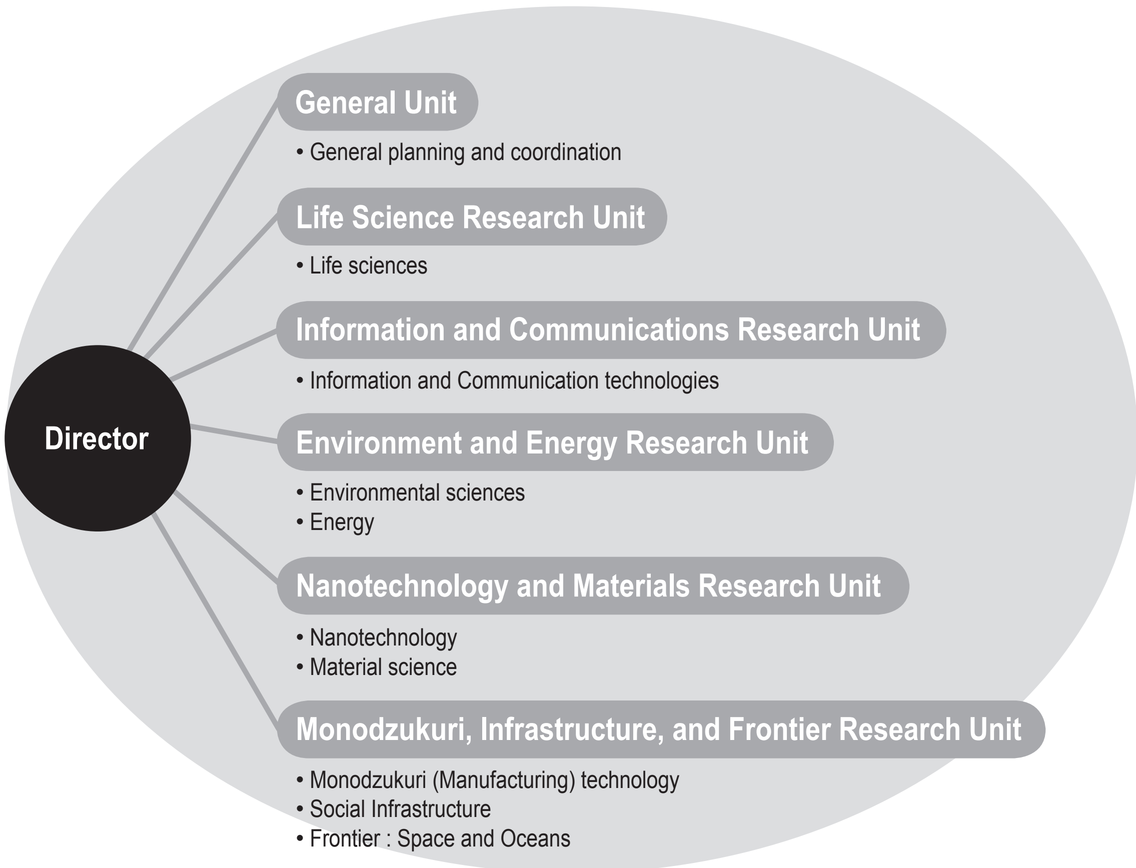
3. S&T foresight and benchmarking

— S&T foresight is conducted every five years to grasp the direction of technological development in coming 30 years with the cooperation of experts in various fields.

— International Benchmarking of Japan's science and engineering research also implemented periodically.

— The research results are published as NISTEP report.

Organization of the Science and Technology Foresight Center



＊Units comprise permanent staff and affliated fellows
＊The Center's organization and responsible are reviewed as required

NISTEP

Science & Technology Foresight Center

National Institute of Science and Technology Policy (NISTEP)

Ministry of Education, Culture Sports, Science and Technology, JAPAN

Science and Technology Trends — Quarterly Review 2009. 7