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Science & Technology Trends

Quarterly Review

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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

INVITATION

As described in the Foreword on the first page, we have been publishing "Quarterly Review" as the English version of Japanese "Science and Technology Trends" since 2002.

Unfortunately, we have to announce that this 38th issue of Quarterly Review will be the last issue as printed material. Thank you very much for reading and making use of the Review in your research activities.

Instead, we are happy to also announce that we are going to start issuing Quarterly Review as e-mail newsletter from April, 2011. The contents will be perfectly the same as before, and furthermore, we expect that we are going to convey more information more in a timely manner for you.

Therefore, we would like to invite you to enroll as a recipient of this new e-mail newsletter service. Once enrolled, you will be able to receive the latest issue of Quarterly Review through the Internet every time as soon as the new issue is ready.

You will be able to enroll to the e-mail newsletter through:

stfc@nistp.go.jp

When you send the mail for enrollment, please identify your Name, Mailing Address, your Position and Organization.

I wish that you would keep reading our Quarterly Review and find it useful for your research activities in the future.

For your information, the Quarterly Review including its back issues will be continuously available at the NISTEP website:

http://www.nistep.go.jp/achiev/ftx/eng/stfc/stfc_all-e.html

Incidentally, the Japanese version of Quarterly Review (Science and Technology Trends) will be continuously published as printed materials as well as through NISTEP website:

(http://www.nistep.go.jp/achiev/ftx/jpn/stfc/stfc_all-j.html)

If you prefer to have Japanese Science and Technology Trends sent to you, please contact us through the above address for enrollment.

Executive Summary

Life Sciences

1 Trends in Molecular target therapy for Lung Cancer

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Molecular target therapy is receiving much interest as an effective way to treat refractory cancers such as lung cancer. Lung cancer is the most fatal cancer in Japan and developed Western countries, accounts for approximately 20% of cancer-related deaths, and has a low 5-year relative survival rate of approximately 30%. Molecular target therapy is designed to improve symptoms by suppressing the function of specific molecules involved in the development and/or progression of the disease, and is categorized as chemotherapy due to the use of chemical agents.

In Japan, three drugs have received sales approval to be used in molecular target therapy for lung cancer, and are used for unresectable progressive/recurrent non-small-cell lung cancer. New molecular target drugs for lung cancer are also being developed, including ones based on the *EML4-ALK* fusion gene, a milestone discovery made by Dr. Hiroyuki Mano of the University of Tokyo/Jichi Medical University. In addition, Dr. Mano and colleagues developed a molecular diagnostic method enabling early lung cancer detection based on *EML4-ALK* fusion gene screening, contributing to the construction of nation-wide diagnostic network.

Concerns for molecular target therapy for lung cancer include the risk of new side effects that never occurred with traditional cytotoxic anticancer agents and the development of drug resistance by cancer cells. Therefore, a thorough investigation of these mechanism and its risks is necessary, and the development of preventative measures for new side effects and drug resistance is an urgent future task, along with the search for new target molecules for lung cancer diagnosis, treatment, and drug development. At the same time, the current medical system needs to be revised, including the guideline on molecular target therapy for lung cancer. In particular, diagnoses based on the *EML4-ALK* fusion gene should be covered by insurance in order to make it more accessible to clinical practice.

(Original Japanese version: published in July 2010)

Information and Communication Technologies

2 Smart Grid as New Big Opportunity of Information and Communication Technology

p.23

The next generation power supply system, holding the promise of gaining higher reliability, lower cost, and reduction of load on the environment by utilizing Information and Communication Technologies (ICT), is often referred to as the Smart Grid. The smart grid may have a greater significance if viewed as an arena for the next stage of developments in ICT industries, providing a new social and economic infrastructure.

In line with the global trend toward low-carbon society, the effort to save energy has become a ubiquitous need in all areas of our activities including our personal lives, business operations, and local societies. The trend has also been giving support globally to accelerate research and development toward commercial realization of the smart grid. It may be relevant to point out here that, in conjunction with the smart grid, a much scaled-up version of a communication network – many-fold greater in scale than the current Internet – is expected to emerge, having a huge impact on the technological and industrial aspects of our society in the future.

In the United States, leading companies in the ICT sector have grouped to enter into technology development and businesses around the smart grid, and the economy in the United States seems to be regarding the areas surrounding it as the next important market for ICT industries. Strategic effort has been increasing with the government working together with the private sector to back up the new moves in the economic quarters: the federal government is proactively implementing measures including capital investment ($45 billion USD in total), promotion of standardization, and legislative preparations. Many entrepreneurial ventures have also been stepping up their activities.

In Japan, on the other hand, although there have been discussions toward realization of a smart community, research and development investment has been focused mainly on renewable energy (e.g. solar power) and storage. The effort toward research, development and commercialization of ICT around the smart grid has not been sufficiently activated. The intrinsic value of a technology can be upgraded only if it is properly defined and developed with the perspective of the grand design, and the vehicle to realize the design in the real world is ICT. In the future, renewable energy technology will evolve in Japan and the technological components may have international competitiveness, but they are likely to be exported as a “part” to be incorporated into upper systems.

We have to see the smart grid in a fresh light: by the arrival of new types of networks, the world of “the Internet of Things” will be expanded beyond the one composed of home electrical appliances and electric vehicles. An all-new concept of “informatization” lies here in that, by bringing the digital infrastructure into close contact with the real world, much improved availability of information, analysis of them, and actions thereupon will finally “push the society and economy in motion,” wherein ICT is expected to find a new evolutionary stage.

(Original Japanese version: published in August 2010)

Environmental Sciences

3

Trends and Problems in Research of Permanent Magnets for Motors — Addressing Scarcity Problem of Rare Earth Elements —

p.40

Enhancing the strength of magnets makes it possible to develop smaller and lighter motors with higher torque, leading to the advancement of energy savings in a range of consumer products such as home electric appliances. As a result, reductions in the power consumption of motors, which accounts for approximately 52% of total domestic power consumption, and in the carbon emissions of next-generation vehicles are expected, as well as enhanced performance of motors for wind-power generation. In fact, the strength of magnets is an important element for promoting green innovation.

In 1983, a neodymium magnet was invented in Japan, and is the strongest in the world, even now. Neodymium magnets for motors are important materials for next-generation vehicles and energy-saving home electric appliances, which are necessary to create a low-carbon society. The urgent issue facing neodymium magnets, for which demand has increased dramatically, is resource risk. In particular, the resource problem of dysprosium (Dy) is serious. Dysprosium is used in magnets for the motors of next-generation vehicles, in which the motors are exposed to a high-temperature environment.

Since 1917, when an artificial permanent magnet was first produced, more than 10 kinds of magnets have been invented. The research and development of magnets is a long-term challenge, requiring 20 to 30 years to produce a revolutionary discovery or invention. Historically speaking, the inventions of new permanent magnets have been brought about by bold interdisciplinary ideas, passion and chance, and Japanese researchers and Japanese technology have played an important role in such inventions. Most of the revolutionary discoveries and inventions have been put to practical use and are expected to have a major impact on green innovation. Therefore, the provision of public funds for basic and generic research, like the three national R&D projects now being carried out, should be continued and increased. Specifically, a new guiding principle for material development should be obtained by combining structure and mechanism analyses that utilize advanced measuring technology with theoretical analysis that utilizes computing science, in order to promote the discovery of new chemical compounds and organize magnetic alloys. It is desirable to promote these teamwork-type planned research projects in parallel with proposal-based research, based on the free thinking of individual researchers, by encouraging researchers in other fields to participate.

(Original Japanese version: published in September 2010)

Social Infrastructure

4 Development of an Earthquake Early Warning System and Its Benefits

p.55

The Earthquake Early Warning, launched by the Japan Meteorological Agency in October 2007, has been favorably received as a case example in which results of seismic studies have been directly put to beneficial use in peoples' lives. The Earthquake Early Warning (EEW) is a system which, using a nationwide seismic observation network, aims to infer the seismic intensity to be expected at various locations based on earthquake information instantly analyzed at the observation point nearest to the source, and to transmit an alert to those locations before large ground motion arrives there. During the two and a half years from the launch until March 2010, a total of 14 EEWs were issued via television, etc. Although there were some malfunctions caused by erroneous transmissions and seismic intensity prediction errors, the performance of the EEW system more or less fell within the anticipated scope. However, since the time allowance generated by an EEW is just about sufficient from a workable standpoint, how the EEWs' realistic effects can be optimized remains as a future challenge.

The EEWs are divided into Advance Notices and Alerts, depending on the level of the predicted seismic intensity. With the former being intended for expert users in various specific fields, and the latter for general users, the two types of EEWs are used in completely different patterns. Meanwhile, the EEW involves regressiveness whereby the time allowance becomes shorter as the seismic intensity becomes larger. In the case of inland earthquakes, for which the source is nearer to the EEW recipients than that of subduction-zone earthquakes, the EEW generally does not reach the recipients in time for ground motion with a seismic intensity of 6 lower or greater. The figure below, which shows the circumstances at the time of an actual M7.2 earthquake, reveals that the EEW did not reach the recipients in time for strong ground motion within the inner-most circle. In the case of a subduction-zone earthquake, on the other hand, the EEW could generate a time allowance of 10 seconds or more. In particular, the EEW is expected to demonstrate a substantial disaster mitigation effect for the next Tonankai-Nankai Earthquakes for which a seafloor seismic observation network is being developed.

In this manner, the characteristics and the effects of the EEW differ considerably depending on the situation of the users and on the conditions of earthquake occurrence. Since the EEW has only been operated for two and a half years, it has not yet encountered an event where it could fully demonstrate its intended function. Through accumulation of experience, users in their respective standings need to learn the most effective use of the EEW, while understanding its characteristics and limits.

(Original Japanese version: published in September 2010)

Science & Technology Policy

5 Have Past Foresight exercises been able to correctly indicate future directions?

p.71

The National Institute of Science and Technology Policy (NISTEP) conducted the ninth Foresight to probe the direction of the development in science and technology over the coming 30 years. Included in this exercise is a review of the outcomes of the Delphi surveys (a repeated questionnaire for experts, regarding technological development) that were conducted more than twenty years ago (the 1st to 5th survey), as to how many of topics have been realized. The Delphi survey has been a part of every one of the NISTEP's foresight exercises since the first one conducted in 1971.

The review indicates that, on the whole, around 70 percent of the past topics have been realized. Field-by-field examination suggests that fields related to environment, safety, health care and medicine have relatively high realization ratios. On the other hand, fields related to transport and energy show low ratios of realization. The general tendency is that groups of topics that were predicted to be realized at earlier dates scored a high realization ratio, and groups of those with lower degree of importance generally show low realization ratios.

Generally, technical difficulties are cited most frequently as the reason for no realization of a topic. As viewed on a field-by-field basis, technical difficulties have been cited as the main obstacle to realization in many of the topics related to medical and health care. On the other hand, many of the fields related to resources and energy, fields related to infrastructure (transport, construction, and civil engineering), and those related to frontiers (space and marine) cited cost and budgetary issues as well as technical difficulties. The advent of alternative technology is also cited as a reason in fields related to information or electronics, and especially in fields related to communication.

Because of the ratio of realization — around 70 percent — the Delphi survey has a certain level of reliability. On the other hand, it may also be proper to ask ourselves if we, living in the present day, have excellent insights that will be highly appreciated by experts in the future.

(Original Japanese version: published in July 2010)

Science & Technology Policy

6 Main Points of White Paper on Science and Technology 2010

p.83

On June 15, 2010, the "White Paper on Science and Technology 2010 (annual report on the promotion of science and technology in fiscal 2009)" was decided at a Cabinet meeting and was reported to the Diet. The White Paper is a law-based document consisting of two parts. Part 1 focuses on a specific theme every year and Part 2 summarizes the science and technology measures implemented by ministries and agencies in the preceding fiscal year.

Part 1 of the White Paper on Science and Technology 2010 deals with "A new frontier to be extended by value-creating human resources ~ How science and technology should be for Japan to make a new start." "Value-creating human resources" refers to diverse human resources essential for the creation of new values and includes not only researchers and engineers but also persons engaged in the management of universities, research institutes, private corporations and administrative organizations, etc., persons related to intellectual property, persons working in industry-academic-government collaboration, and science and mathematics teachers.

In order to create new value by generating innovation in Japan, it is necessary for diverse human resources to further enhance creativity and productivity. In order to maintain and enhance international competitiveness and the quality of people's life, it is essential to promote science and technology conducive to solving the issues involved in creating a low-carbon society, such as global warming, enhance basic scientific capability, and foster and secure not only researchers and engineers but also "value-creating human resources" engaged in diverse S&T activities. It is also important to enhance the relationship between people/society and science/technology, including the creation of occasions to generate innovation through industry-academic-government collaboration and the promotion of the transparency of and people's participation in policy process.

In recent years, science and technology have increased their role in ensuring national economic growth and affluent national life. In the future, science and technology policy in the world will become science, technology and innovation policy.

Science and Technology White Paper
http://www.mext.go.jp/b_manue/hakusho/html/hpaa.201001/1294965.hlm

(Original Japanese version: published in August 2010)

1

Trends in Molecular target therapy for Lung Cancer

Hiromi OMOE
Life Science Research Unit

1 Introduction

Lung cancer, a refractory cancer, is the most common cause of cancer-related deaths in Japan and developed Western nations, accounts for approximately 20% of overall cancer-related deaths, and has a low 5-year relative survival rate[NOTE 1] of approximately 30% (Figure 1).[1] This is due to the difficulty of early detection and lack of well-established treatment methods that would enable a drastic improvement in the cure rate. Early detection combined with surgical treatment is the classic requirement for it to be cured. However, since lung cancer is often already inoperable and progressive by the time of its detection, up until now, its treatment has been no more than life extension and symptom relief.

With recent progress in molecular biology, the understanding of various disease mechanisms of humans at cellular and molecular levels has improved, resulting in a number of reports identifying molecules involved in the onset and progression of diseases. Accumulated knowledge on various biological molecules and mechanisms involved in the development and progression of cancer is being effectively used for the development of cancer treatments. In particular, in a recent achievement of research and development on molecular target therapy, treatment by blocking the function of targeted biological molecules involved in the abovementioned cancer, has been dramatic. It is hoped that molecular target therapy will become an effective method to treat refractory cancers such as progressive cancer and lung cancer, which are untreatable with traditional anticancer drugs, and that it will bring about personalized medicine, providing the best treatment for individual patients.[NOTE 2]

Here, I will introduce the trends in molecular target therapy, focusing on the treatment for lung cancer. First, I will discuss the importance of lung cancer treatment for Japanese and international healthcare from the epidemiological perspective. Then, I will introduce the status of molecular targeting treatment within overall cancer treatment as well as within lung cancer treatment. Finally I will exemplify the discovery and clinical application of therapeutic target gene *EML4-ALK* for lung cancer, discovered by Dr. Hiroyuki Mano of the University of Tokyo/Jichi Medical University, as a significant achievement of recent years.

2 The importance of lung cancer treatment – an epidemiological perspective

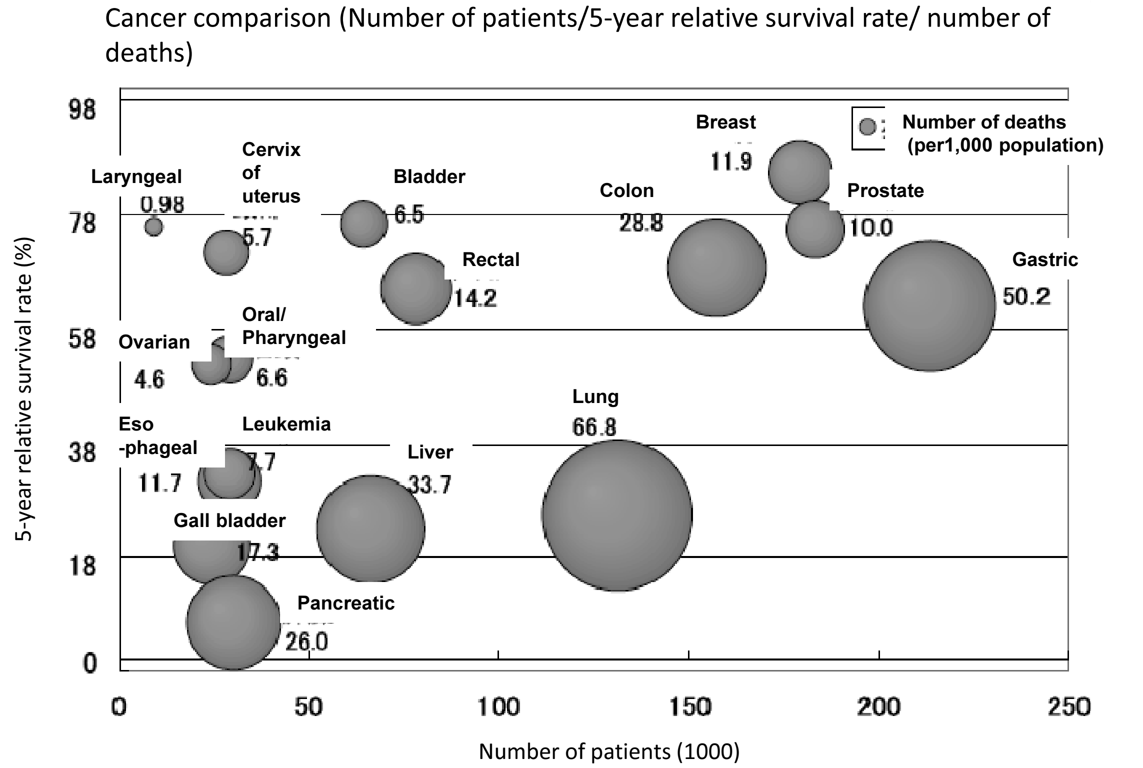
According to an estimation by the World Health Organization (WHO), in 2007, 7.9 million people died of cancer, representing approximately 13% of the total

[NOTE 1] : 5-year relative survival rate

The index of the proportion of people diagnosed with cancer who survive 5 years compared to the proportion of the Japanese population in general who are still alive in 5 years. The general Japanese population in this case indicates the Japanese population adjusted for the distribution of gender, birth year, and age.

[NOTE 2] : Personalized medicine

Treatment planning selecting for the most effective drugs, doses, and administration methods with the fewest side effects based on an investigation of an individual patient's physical characteristics and its relationship to the disease based on genetic testing etc. Since molecular target therapy is provided based on information on genetic abnormalities and excessive expression of its products, it leads to personalized medicine (mentioned later in 3-2).



[Reference]
Number of patients: *2008 Patients Survey* (Ministry of Health, Labor and Welfare)
5-year relative survival rate: *Cancer Statistics '09*: Survival rate of regional cancer registry (1997~1999 diagnostic cases) (Foundation for Promotion of Cancer Research)
Number of Deaths: 2008 *Vital Statistics* (Ministry of Health, Labor and Welfare)

Figure 1 : The number of cancer patients and the survival rate
Source: Cabinet Office, the Second Life Innovation Task Force Data Collection[1]

deaths around the world and confirming cancer as a major cause of death worldwide. In particular, lung cancer contributes to a significant portion of cancer-related deaths. The American Cancer Society's (ACS) *Global Cancer Facts & Figures* 2007 estimated that approximately 975,000 males and 376,000 females died of lung cancer in 2007, and reported that lung cancer was the leading cause of death in men and 2nd leading cause of death in women among all cancer-related deaths.

As for regional factors, according to the ACS, lung cancer is the most common cause of cancer-related death in Central, North, and South Americas, European nations, and Australia. In addition, lung cancer is the most fatal cancer in Asia outside of the South and Central regions. Specifically, taking the U.S. as an example, the U.S. Centers for Disease Control and Prevention (CDC) reported that 89,243 males and 69,356 females died of lung cancer in 2006.

Also in Japan, lung cancer is a significant cause of death. Since cancer replaced cerebral vascular diseases and cardiac diseases as the most common cause of death in 1981, the number of cancer-related death keeps increasing. Within these cancer-related deaths, lung cancer has been the most common since it replaced gastric cancer in 1998. In 2008, 342,963 people died of cancer, within which, 66,849 people, 19.5% of overall cancer-related deaths, died of lung cancer.[2]

Changes in the mortality rate, excluding the effect of age-distribution changes (the age-adjusted death rate[NOTE 3]), show that the overall death rate from cancer is decreasing in Japan. However, the death rate from lung cancer has remained constant (Figure 2). In addition, there is a gender difference in the death rate of lung cancer, which is higher in males by a magnitude of 3 to 4 times.

To summarize, since lung cancer causes a significant

[NOTE 3] : Age-adjusted death rate

Death rate calculated with a standardized population to exclude the effects of the population's age structure. In Japan, the "1985 model population" is often used as the standardized population.

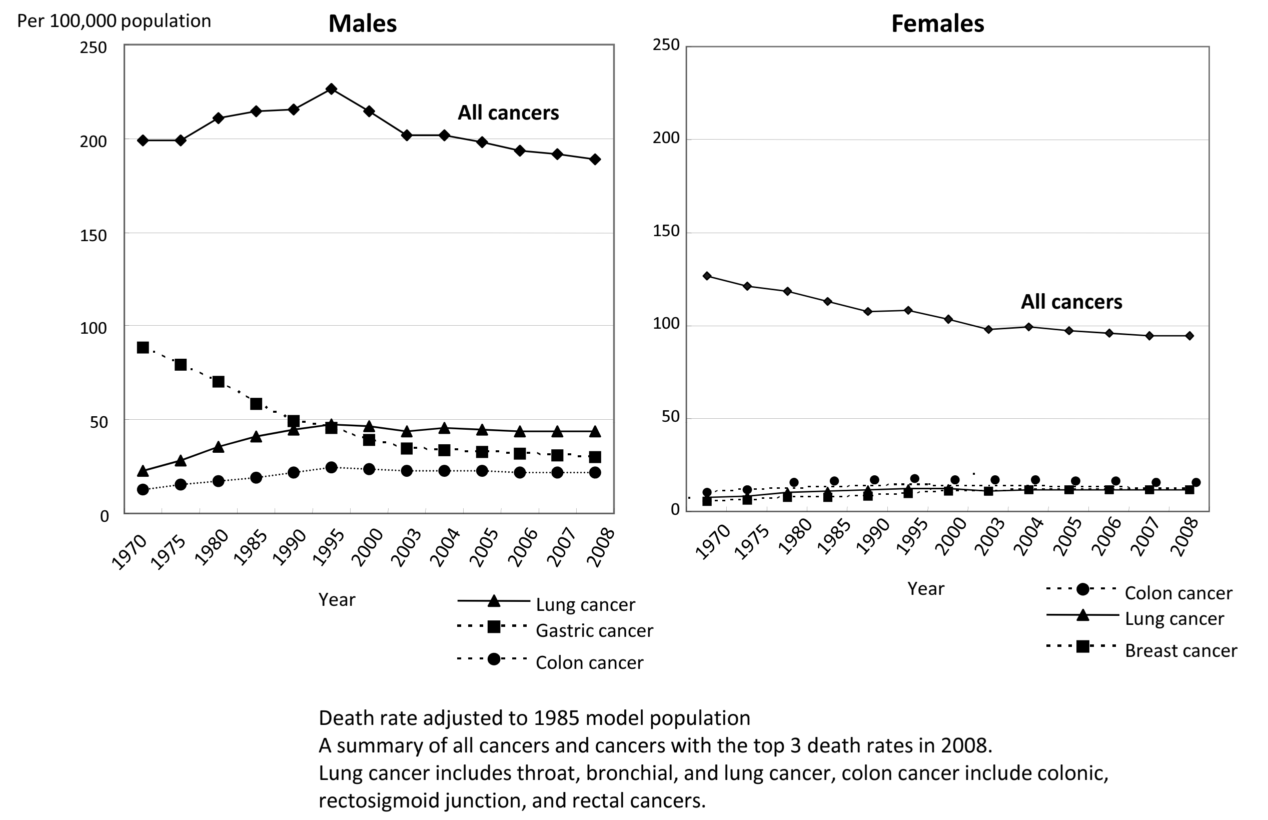


Figure 2 : Transitions of Age-Adjusted Cancer Deaths in Japan

Produced by the STFC based on reference[2]

number of deaths worldwide, the development of effective therapeutic methods to treat lung cancer would be beneficial to Japanese as well as global healthcare.

3 Characteristics of molecular target therapy and its status within cancer treatment

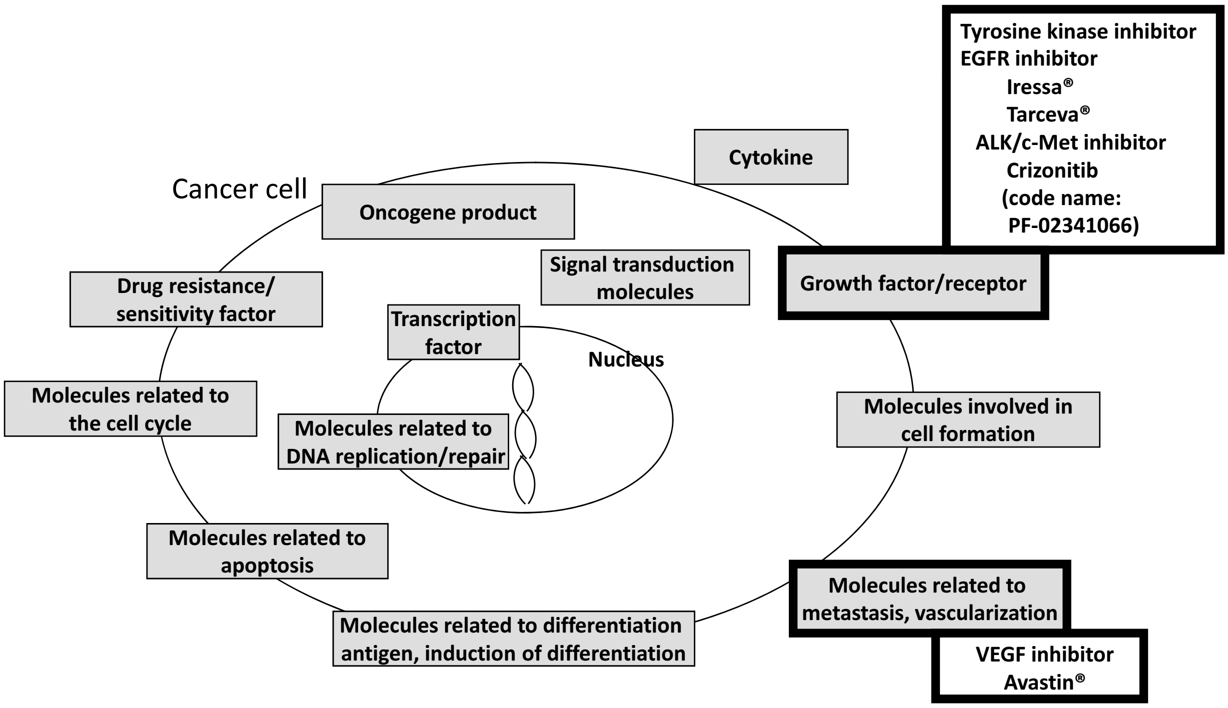
3-1 Characteristics of molecular target therapy

Molecular target therapy aims to improve symptoms and to heal the disease by suppressing specific molecules involved in the development and progression of the disease. It uses medication – molecular target drugs – designed or selected to suppress/ block the functions of specific molecules. Therefore, molecular target drugs are developed by targeting specific molecules based on the assumption that the suppression of those specific molecules will treat the disease. Target molecules of the drug can be a single molecule or a group of molecules with similar molecular structures, and the drugs targeting the latter are called multi-target drugs.

Molecular target drugs include low molecular drugs targeting molecules inside the cell, and antibody drugs targeting protein and/or sugar chains on the cell surface. These drugs are indicated for a wide range of diseases. For example, antibody drugs on the market or in post-phase III clinical trials have a variety of indications for autoimmune disease such as rheumatism, cancer and related diseases, cardiovascular diseases, infectious diseases, neurological diseases, asthma, and osteoporosis.[3]

3-2 Status within cancer treatment

Cancer therapy consists of three major types of treatments: surgical and radiation therapy as a local treatment, chemotherapy as a systemic treatment, and a combination of these treatments, multi-modality therapy, is the common treatment of cancer clinically. In addition to these three major types of treatment, immunological therapy and gene therapy have been developing in recent years and their clinical application is progressing. Each therapy is selected based on the type of cancer (which organ is affected), the stage of cancer (cancer progression), and the histological type (pathological category of cancer), as well as the patient's medical history and general status. Refer to the report on Science & Technology Trends by Dr. Shoji et al. for details on cancer treatment.[4]



EGFR: Epithelial growth factor receptor (tyrosine kinase), VEGF: Vascular epithelial growth factor, ALK/c-Met: Anaplastic lymphoma kinase (tyrosine kinase)/ hepatocyte growth factor receptor (tyrosine kinase)
This is a simplified image, and the positions of each molecule do not reflect their actual site of expression.
Bold frames show drugs introduced in this report.

Figure 3 : Examples of therapeutic target molecules and molecular target drugs for cancer

Produced by the STFC based on reference[5]

Many of traditional anticancer drugs are cytotoxic, and treatment that uses medication is termed chemotherapy. Molecular target therapy is categorized as chemotherapy for its use of medication.

Molecular target therapy for cancer uses molecular target drugs that suppress/ block the function of biological molecules involved in the pathogenesis, progress, and metastasis of cancer. Figure 3 shows candidate biological molecules that are the targets of cancer treatment.[5] Target molecules in cancer treatment varies widely, in other words, cancer pathogenesis and malignant alteration are induced by a complex molecular mechanism, which makes up the “character” of an individual cancer. Therefore, this treatment requires a diagnosis of this character to see if medication targeting specific molecules will be effective. To achieve this, patients need to be clinically screened for abnormalities in the biological molecules involved in cancer or in the genes coding these molecules before treatment is provided. Because of this, molecular target therapy is expected to progress into personalized medicine.

The status of molecular target therapy within cancer treatment becomes clearer when the side effects of molecular target drugs and traditional cytotoxic drugs are compared. General cytotoxic agents kill cancer cells by blocking DNA synthesis or cell division in cells with frequently repeated cell divisions. Since the drug attacks healthy cells as well as cancer cells, continuous treatment often becomes difficult due to a variety of side effects such as the loss of hair, nausea, vomiting, gastrointestinal tract disturbances, and hematotoxicity. However, since molecular target drugs only suppress/block the activity of specific molecules, it is believed that the side effects, like ones caused by cytotoxic drugs, can be reduced. However, the risk of new side effects have been reported with the progress of its clinical use. Gefitinib (Iressa®), a molecular target drug for lung cancer has been reported to have caused severe lung disorder (mentioned in 4-3).

4 Trends in molecular targeting treatment in lung cancer

In this chapter, I will describe molecular target therapy specific to lung cancer.

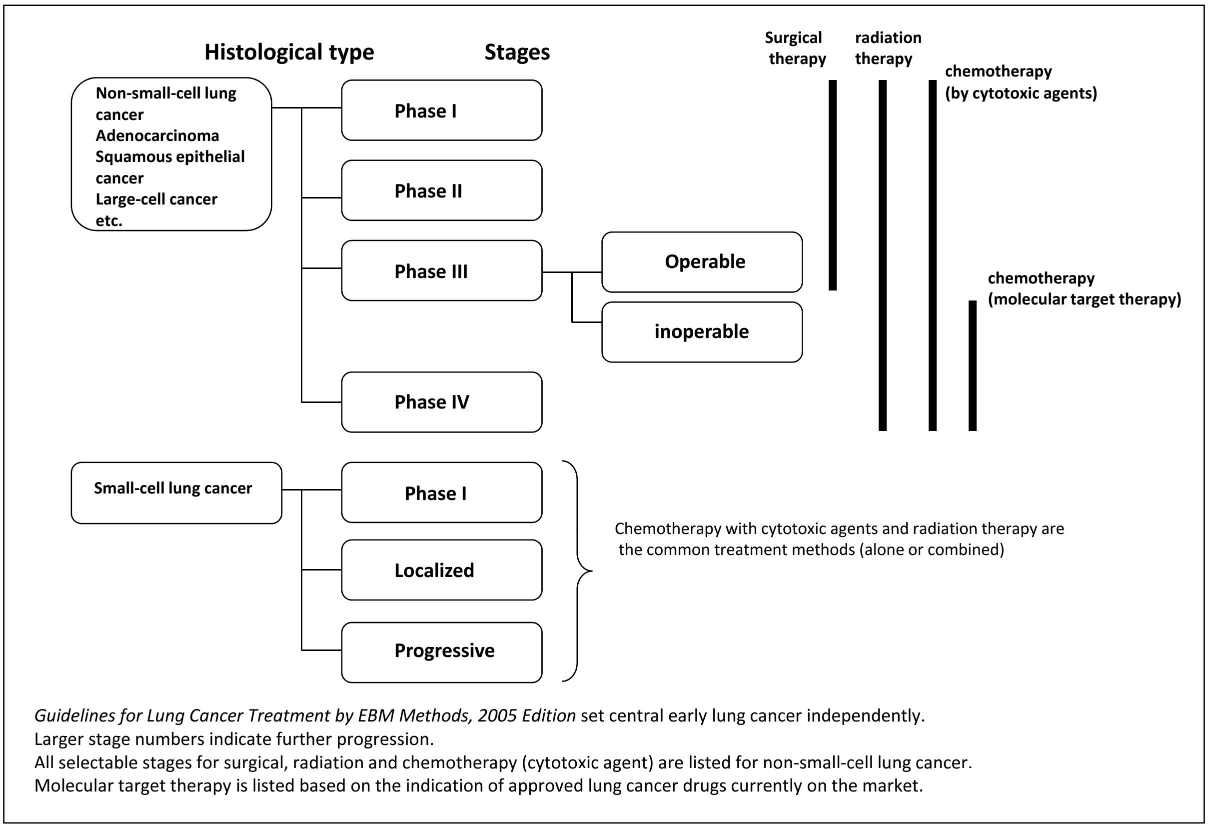


Figure 4 : The relationship between the histological type and stage of lung cancer indicated *in Guidelines for Lung Cancer Diagnosis* (excluding recurrence)

Produced by the STFC based on reference[5]

4-1 General Treatment Strategy for Lung Cancer

As with other cancer treatments, the basic direction of lung cancer treatment is selected based on the histological type and stage of cancer progression. In particular, the two histological types, small-cell lung cancer and non-small-cell lung cancer, have been important factors in the treatment protocol for lung cancer. Histological type can be determined by histopathological examination of expectorated sputum or cells obtained from the focus in the lung. Small-cell lung cancer is named after the small size of cancer cells compared to the cells of other types of lung cancer. Non-small-cell lung cancer indicates lung cancer other than small-cell lung cancer, and is further categorized to adenocarcinoma, which frequently occur in the peripheral of the lungs, squemous cell cancer, which frequently occurs near where bronchia enters the lungs and large-cell cancer, which proliferate rapidly resulting in a large cancer by the time of detection. The latter, non-small-cell lung cancer takes up 85~90% of total lung cancer in Japan. In addition to small-cell lung cancer and non-small-cell lung cancer categorization, the stage of lung cancer is examined before selecting the treatment methods.

Treatment of lung cancer is indicated in *Guidelines for Lung Cancer Treatment by EBM Methods, 2005 Edition* published by the Japan Lung Cancer Society,[6] an NPO. These guidelines indicate the principles of Evidence Based Medicine (EBM) and standard lung cancer treatment methods. The relationship between the histological type and the stage of lung cancer is indicated in Figure 4. Therefore, surgical treatment, radiotherapy, and chemotherapy are not set up on one-on-one basis with each histology-stage relationship but rather, with multiple methods and multiple chemotherapy agents.

Currently, molecular target therapy is practiced only in non-small-cell lung cancer (Figure 4). The three molecular target drugs for lung cancer that have been approved in Japan have indications for inoperable (Stage III~IV in Figure 4) or recurrent non-small-cell lung cancer. On the other hand, molecular target therapy is not practiced for small-cell lung cancer due to lack of effective molecular target drugs. For small-cell lung cancer, chemotherapy using traditional cytotoxic drugs and radiotherapy are used as effective methods.

4-2 Characteristics and Uses of Molecular target drugs for Lung Cancer

Here, I will discuss molecular target therapy for non-small-cell cancer, focusing on the characteristics and the uses of molecular target drugs used for general practice in Japan.

There are three drugs for lung cancer treatment with sales approval in Japan; gefinitib (Iressa®), which was approved in Japan before any other countries in July 2002, erlotinib (Tarceva®), which was approved in October 2007 and bevacizumab (Avastin®) (approved in June 2010). Of these drugs, Iressa® and Tarceva® are low molecular drugs, and had been used to treat over 85,000 lung cancer patients by April 2009 in Japan. Avastin® is an antibody drug which was approved for colon and rectal cancers in April 2007, and its indication was subsequently expanded to include lung cancer in November 2009. All three drugs are used for non-small-cell lung cancers that are inoperable or recurrent. Of the three drugs, Iressa® received sales approval from the U.S. Food and Drug Administration in May 2003, however, its use for new patients was basically banned in June 2007. On the other hand, in the EU, drug developer AstraZeneca of the UK had its application to the European Medicines Evaluation Agency (EMEA) for sales approval in January 2005 turned down, however, the company reapplied in May 2008, and EMEA approved it in July 2009. The reason behind this difference is that the clinical efficacy of Iressa® was reported to vary greatly depending on the background of the patient, in regard to factors such as ethnicity and genetic information, in previous global studies (ISEL, INTEREST, IPASS etc). Clinical efficacy here points to survival benefit indexed by survival period and survival rate, response rate indicating the effect of reducing cancer, and the recurrence suppression effect measured by relapse-free survival period and recurrence rates.

Iressa® and Tarceva® are low molecular drugs targeting the receptors of epidermal growth factor (EGF), known as a cellular proliferation/growth factor (Figures 3 and 5). EGF receptors are transmembrane molecules (glycoprotein), and are a class of receptor tyrosine kinases (EGFR tyrosine kinase) which specifically phosphorylate residues of tyrosine, an amino acid. In some types of lung cancer, *EGFR* tyrosine kinase coding gene (*EGFR* gene) mutation is reported to cause abnormal activation of EGFR tyrosine kinase, and the abovementioned two drugs block the EGFR tyrosine kinase activity.

Abnormal activity of tyrosine kinase, including EGFR, is believed to be one of the causes of various cancers including lung cancer. Tyrosine kinases usually play a central role in the proliferation mechanism of normal cells, taking charge of the regulation of "growth/proliferation factor (extracellular cellular proliferation signals) -> tyrosine kinase -> activation of intracellular proliferation signal transmission" pathway (Figure 5). This pathway is suppressed when there is no stimulation by extracellular cellular proliferation signaling molecules, and is transiently activated only when there is stimulation by cellular proliferation signaling molecules. However, when the pathway becomes constantly active due to the disruption of the pathway regulation caused by amplification, mutation, and/or structural changes in the tyrosine kinase coding gene, there will be a continuous intracellular proliferation stimulus. Subsequently, this is believed to lead to unlimited cellular proliferation.

Since tyrosine kinase is involved in the fundamental life-sustaining process, regulation of cell proliferation, there has been a concern that drugs blocking such molecules may produce some grave side effects. However, since cells of certain types of cancer caused by *EGFR* gene mutation including lung cancer are much more sensitive to tyrosine kinase blocking compared to normal cells, it has been shown that drugs blocking the molecules swiftly produce effects only on cancer cells.

From global clinical trials and clinical experience after marketing, Iressa's® clinical effect for lung cancer is suggested to vary with the background of the patient, including factors such as ethnicity, gender, histological type of cancer and smoking history.[7] In detail, it is more effective in Asians compared to Caucasians, and more effective on adenocarcinoma out of all non-small-cell lung cancers, and also on females and non-smokers. It is also reported that clinical efficacy is high on lung cancer patients with mutation of the *EGFR* gene, the gene coding EGFR tyrosine kinase, the target of Iressa®. *EGFR* gene mutation is found in many lung cancers in Asians, adenocarcinoma and lung cancer in non-smokers, which makes Iressa® effective. In clinical trials with Japanese lung cancer patients with *EGFR* gene mutation as the subjects, which were publicized in

June 2010, the clinical effects of Iressa® were shown to be significantly higher than those of standard chemotherapy using traditional cytotoxic drugs.[8] In this trial, clinical efficacy was measured by a progression-free survival period, which is the amount of time survived without progression. To sum up the report, *EGFR* gene mutation is perceived as a prediction factor for the treatment efficacy of Iressa®. Therefore, it is useful to check the presence of *EGFR* gene mutation before initiating treatment with the drug, and only those with such mutation should be treated. *EGFR* gene mutation screening was approved for coverage by insurance in June 2007 in Japan, and it is clinically practiced as a bench mark to judge an indication for Iressa®. To check the presence of *EGFR* gene mutation, various methods are being developed based on the direct sequence method and PCR (polymerase chain reaction). In addition, the sensitivity/specificity differences and equivalence among the checking methods are currently being examined.[7]

Since Tarceva® targets EGFR tyrosine kinase, its mechanism of efficacy is believed to be similar to that of Iressa®. However, it is different from Iressa® in that it was shown to have a survival benefit for non-small-cell lung cancer patients in clinical trials abroad. The clinical effects of Tarceva®, similar to Iressa®, are higher in lung cancer in Asians, lung adenocarcinoma, lung cancer in non-smokers, and lung cancer patients with *EGFR* gene mutation, however, there is a report claiming that *EGFR* gene mutation and clinical effect do not correlate. In addition, there is a report that Tarceva® is clinically effective for lung cancer with histological type other than adenocarcinomma, lung cancer of smokers, and lung cancer patients without *EGFR* gene mutation. The difference in clinical effects between Tarceva® and Iressa® as well as criteria for the use of Tarceva® will be clarified by the vigorous clinical trials which are currently underway.

Avastin® is an antibody drug (human monoclonal antibody) targeting vascular endothelial growth factor (VEGF). VEGF is a glycoprotein involved in vascularization, which is a critical process for cancer growth and metastasis. VEGF expression increases in various types of cancer including lung cancer and colon cancer, and the correlation between its expression and stages and prognosis of cancer has been reported. Avastin® was approved in the U.S. in February 2004 and in the EU in January 2005 for treating colon cancer as the first vascularization blocker in the world, and its indication was expanded to lung cancer in the U.S. and the EU as well as in Japan. It is approved for breast cancer and kidney cancer in the U.S. and the EU. Domestic clinical trials as well as those abroad with lung cancer patients as their subjects showed that the combination of Avastin® and CP therapy, a combination of carboplatin and paclitaxel used in standard chemotherapy, was affective in both Asian and western lung cancer patients.

4-3 Side Effects of and Drug Resistance to Molecular target drugs for Lung Cancer

As much as the clinical effectiveness of molecular target drugs such as Iressa® in treating lung cancer has been shown, there are still concerns about the risk of new side effects not seen with traditional cytotoxic

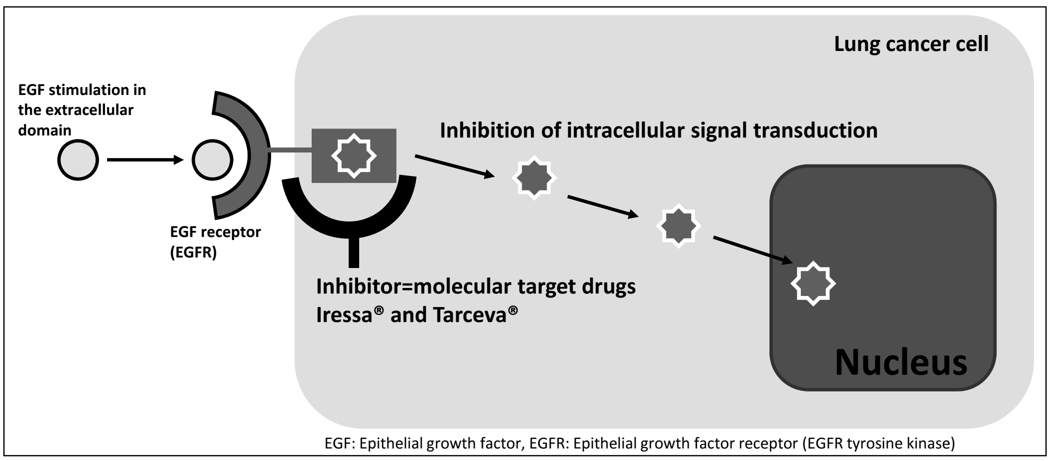


Figure 5 : Effective mechanisms of molecular target drugs for lung cancer, Iressa® and Tarceva®

Produced at the STFC based on the lecture by Dr. Mano anticancer drugs and about drug resistance.

As for side effects, there have been reports of death caused by acute lung injury and interstitial pneumonia with the use of Iressa®. With consideration to the risk of such side effects and the clinical effects of the drug on lung cancer patients with *EGFR* gene mutation shown in 4-2, the Japan Lung Cancer Society has published its *Guidelines on Gefinitib Use* (revised on July 25, 2005) to increase the benefit/risk ratio. At the same time, death caused by interstitial pneumonia has been reported with the use of Tarceva®. Avastin® carries the risk of lung bleeding, and thus is contraindicated for use on patients with squamous epithelial lung cancer and on patients with a history of hemoptysis.

As for resistance to the drugs, patients clinically suited for Iressa® and Tarceva® acquire resistance within a year to a few years and the cancer recurs in almost all cases.[9] Additional *EGFR* gene mutation has been proposed to lower the drug binding to EGFR tyrosine kinase leading to the drug resistance, and investigation on the detailed mechanisms and drug development to overcome the resistance are underway.

5 New Molecular Target Therapy for Lung Cancer -The discovery of the *EML4-ALK* fusion gene and its clinical application-

The efficacy of molecular target drug Iressa®, which blocks the activity of EGFR tyrosine kinase in lung cancer patients with *EGFR* gene mutation, was introduced in the last chapter. This efficacy indicates that the identification of the molecules causing lung cancer and drugs interfering with the activity of the molecule will result in an effective molecular target therapy. However, as discussed in 3-2, target molecules for cancer treatment vary widely, and there have been a great efforts in basic research inside and outside of the country, such as the search for and analysis of new target molecules in lung cancer treatment. Here, I will introduce a significant achievement in recent years, the discovery of *EML4-ALK*, a therapeutic target gene, by Dr. Hiroyuki Mano of the University of Tokyo/ Jichi Medical University and its clinical application as molecular target therapy.

*5-1 The Discovery of a Therapeutic Target Gene -**EML4-ALK** Fusion Gene-*

To discover a new oncogene causing lung cancer, Dr. Mano et al. started with uniquely upgrading and developing the method for screening oncogenes from patients' specimens. This method makes almost all genes contained in a patient's specimen to be forcibly expressed inside fibroblast cells using retrovirus vector (Figure 6). The isolation of oncogene from the transformed focus, in other words, focus formation assay, was one of the methods dominating medical research in the 1980s, however, organ specific oncogenes, expressed only in a specific organ, could not be isolated at the time. In order to achieve this, Dr. Mano et al. established a method to screen oncogenes by forcibly expressing almost all of the genes contained in a patient's specimen based on a report by Dr. Moriuchi and his colleagues[10] at Nagasaki University, and reported this in 2007.[11]

Using this gene screening method, Dr. Mano et al. discovered a new oncogene, a candidate for therapeutic target, the *EML4-ALK* fusion gene, from the specimen of the non-small-cell lung cancer (adenocarcinoma) of a 62-year old smoker, and reported it in Nature on August 2, 2007.[12] The *ALK* gene codes for a tyrosine kinase named anaplastic lymphoma kinase (ALK), and the *EML4* gene codes for microtubule associated protein EML4, and normally, their products, ALK tyrosine kinase and EML4 protein, are present independently inside normal cells. However, when the *ALK* gene and the *EML4* gene fuse, abnormally active EML4-ALK tyrosine kinase is produced by the *EML4-ALK* fusion gene (Figure 7) and is believed to cause lung cancer. In fact, *EML4-ALK* fusion gene has been shown to be present only in lung cancer cells. Please refer to the reference[12] as well as open patent information from Japan and the U.S. (Japanese Published Unexamined Application No.2008-295444, U.S. Patent application publication No.2009/099193 etc) for details of *EML4-ALK* fusion gene.

Lung cancer caused by EML4-ALK tyrosine kinase has been confirmed in animal studies. In transgenic mice with the *EML4-ALK* fusion gene expressed specifically in alveolar epithelium, making the lungs produce EML4-ALK tyrosine kinase, and developed a few hundred lung adenocarcinoma simultaneously in both lungs within a few weeks after birth.[13] The abnormal activity of tyrosine kinase had been already known to be carcinogenic in the case of EGFR (refer to 4-2), and EML4-ALK tyrosine kinase further confirmed it.

In normal human cells, since the *ALK* gene and the *EML4* gene are located close to each other on chromosome 2 in opposite orientations, fusion of these genes observed in lung cancer cells indicates a structural abnormality of the chromosome. Using the genomic DNA of lung cancer patients, Dr. Mano et al revealed that the chromosome sandwiched between *ALK* gene and *EML4* gene gets excised and subsequently the *ALK* gene and the *EML4* gene are bound in revered orientation and become fused.

Examples of cancer caused by abnormally active tyrosine kinase production triggered by its gene fusing with another gene due to chromosomal structural abnormality are hematological cancers such as chronic myelocytic leukemia and anaplastic large cell lymphoma. Chronic myelocytic leukemia is believed to be caused by production of abnormally activated BCR-ABL tyrosine kinase due to an Abelson leukemia tyrosine kinase coding gene, the *ABL* gene, fusing with the *BCR* gene at the breakpoint cluster region (the *BCR-ABL* fusion gene) triggered by the structural abnormality of the chromosome. This structural abnormality in the chromosome is called Philadelphia chromosome. Currently, low molecular drug imanitib (Glivec®), which blocks abnormally activated BCR-ABL tyrosine kinase, is used as a first-line therapy in chronic myelocytic leukemia. In addition, anaplastic large cell lymphoma is believed to be caused by the production of abnormally activated NPM-ALK tyrosine kinase due to abovementioned *ALK* gene fusing with the nucleophosmin-anaplastic lymphoma kinase (NPM) coding *NPM* gene, triggered by a chromosomal structural abnormality.

On the other hand, fusion of genes caused by chromosomal abnormality was generally believed to cause hematological cancers, but not solid cancers such as lung cancer. Dr. Mitelman et al. reported in 2004 that there was a possibility that chromosomal structural abnormality maybe a major cause of solid cancer,[14] however, it was not until the reports by Dr. Mano et al. in 2007 on lung cancer[12] and by Dr. Tomlin et al. on prostate cancer[15] that this was verified. The discovery of fusion gene *EML4-ALK*, which caused lung cancer, had a great academic impact, and was selected as one of 10 most important medical discoveries of the year in the December 2007 issue of Nature Medicine.

There are two important matters of clinical significance regarding the discovery of *EML4-ALK* fusion gene. One of them is the implementation of early lung cancer detection and the other is a potential for new molecular target drug development for lung cancer. Diagnosis and drug development are discussed below.

5-2 Development and Clinical Application of New Lung Cancer Diagnostic Methods

As mentioned in 4-1, lung cancer has been traditionally diagnosed based on pathohistological testing using specimens such as expectorated sputum. However, the sensitivity of such examinations is low. For example, expectorated sputum has to contain at least a few percent of cancer cells in 1ml of sample for a diagnosis. This means that in many cases, lung cancer has already progressed by the time of its diagnosis, and a method for detecting lung cancer with a higher level of sensitivity was long been awaited.

Dr. Mano et al. have developed a molecular diagnostic method for lung cancer using reverse transcription polymerase chain reaction (RT-PCR).[12] This method detects the mRNA of *EML4-ALK* fusion gene which is only present in lung cancer cells. Its sensitivity is much higher than the traditional sputum examination, and it is able to detect lung cancer with only 10 cancer cells within 1ml of sputum sample.

In March 2009, Dr. Mano et al. founded the ALK Lung Cancer Study Group (ALCAS) in order to develop a nation-wide diagnostic network structure for lung cancer patients in Japan. ALCAS is carrying forward the abovementioned multiplex RT-PCR with improved sensitivity for *EML4-ALK* mRNA detection[16] as well as the intercalating antibody-enhanced polymer method (iAEP method), which detects abnormally activated EML4-ALK tyrosine kinase with a high sensitivity[17] as a lung cancer diagnostic screening. Multiplex RT-PCR is an exhaustive detection method able to detect even the mRNA of *EML4-ALK* fusion genes variants, enabling early detection of lung cancer from samples such as pleural effusion, bronchial lavage fluid, and frozen specimen as well as sputum.

ALCAS has investigated the presence of the *EML4-ALK* fusion gene in 220 patients with non-small-cell lung cancer using multiplex RT-PCR. As a result, the *EML4-ALK* fusion gene was detected in 11 patients, all of whom had adenocarcinoma, accounting for 5% of

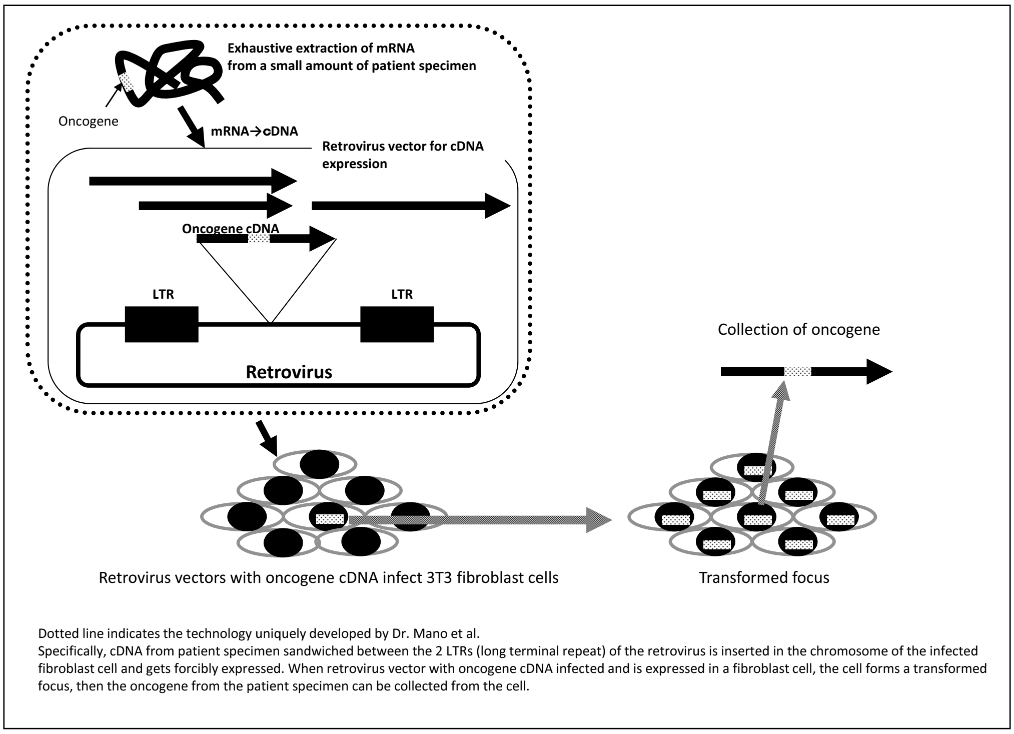


Figure 6 : Method of oncogene screening from patient specimen independently improved and developed by Dr. Mano and et al.

Produced by the STFC based on the lecture by Dr. Mano

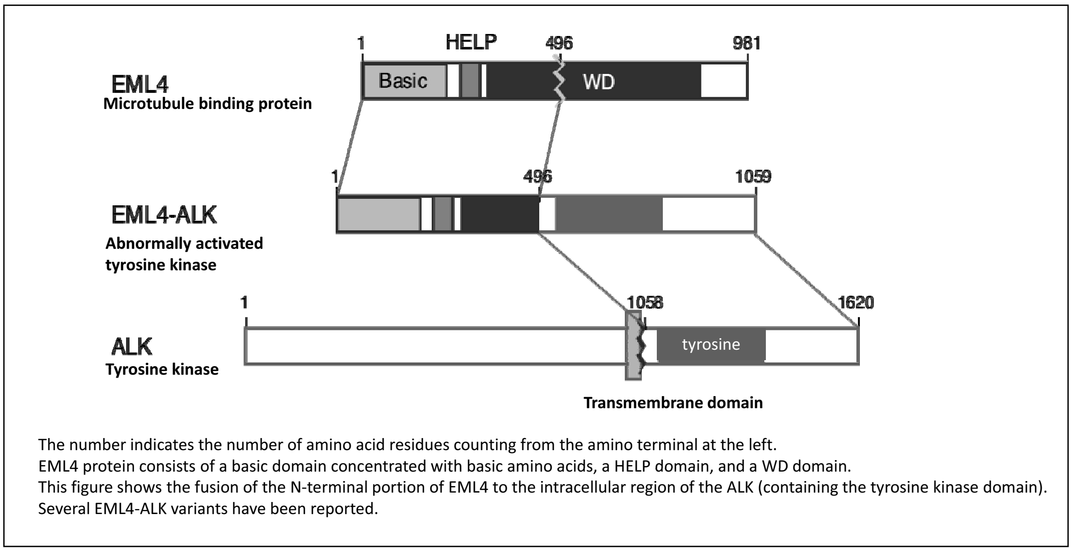


Figure 7 : Structure of EML4-ALK tyrosine kinase produced by *EML4-ALK* fusion gene

Produced by the STFC based on the lecture by Dr. Mano

the subjects of non-small-cell lung cancer. In addition, the detection rate of the *EML4-ALK* fusion gene was higher in patients with non-small-cell lung cancer below the age of 50, accounting for 35% of the total.[18] Meta-analysis of research data obtained inside and outside the country up to date, including past research done by Dr. Mano et al., showed that the *EML4-ALK* fusion gene was present in 3% to 7% of non-small-cell lung cancer in Asians (Japanese, Korean, Chinese).[19] As mentioned before, approximately 63,000 Japanese patients die from lung cancer annually, 85% to 90% of which are from non-small-cell lung cancer, and early detection of 5% of these patients and provision of molecular target therapy would save over 2500 patients annually, thus its clinical value is extremely high. In particular, the diagnosis of patients with non-small-cell lung cancer who are under the age of 50 is significant considering the high detection rate of the *EML4-ALK* fusion gene in this age group.

In addition, it is shown that patients with the *EML4-ALK* fusion gene and those with *EGFR* gene mutation do not overlap.[12] In other words, *EGFR* gene mutation and the *EML4-ALK* fusion gene have a mutually exclusive relationship. Therefore, it is necessary to conduct testing to detect the presence of *EGFR* gene mutation and the *EML4-ALK* fusion gene before starting a molecular target therapy, in order to judge the appropriate indication for Iressa®, Tarceva®, and *ALK* inhibitors shown in 5-3.

5-3 Development of New Drugs for Lung Cancer

Molecular target drugs for lung cancer, Iressa® and Tarceva®, and Glivec® for chronic myelocytic leukemia all block abnormally activated tyrosine kinase. This means that blocking the central cause of carcinogenesis, abnormal tyrosine kinase, is at the basis of its effective molecular targeting treatment. Therefore, EML4-ALK tyrosine kinase that has been abnormally activated by the fusion of ALK tyrosine kinase and EML4 protein can be a therapeutic target molecule.

Dr. Mano et al. reported, in December 2008, that EML4-ALK tyrosine kinase could be a possible candidate as a therapeutic target molecule for lung cancer treatment.[13] Transgenic mice expressing EML4-ALK tyrosine kinase specifically on the lung alveolar epithelium develop severe lung cancer. When 2,4-pyrimidinediamide, a ALK tyrosine kinase specific blocker, was administered orally to these mice, most of the cancer disappeared within 25 days. Lung cancer caused by EML4-ALK tyrosine kinase was experimentally verified to be treatable by specific inhibition of ALK tyrosine kinase.

Taking the above experimental results, molecular target drug inhibiting ALK tyrosine kinase was developed and is currently undergoing clinical trials. Among the drugs being developed by multiple companies, crizotinib (code name: PF-02341066) developed by Pfizer Inc. is at the forefront of clinical trials. Crizotinib is a multi target drug (refer to 3-1) which targets the molecules ALK tyrosine kinase and c-Met. c-Met is a receptor for hepatocyte growth factor (HGF), and is also a tyrosine kinase like ALK. In the phase I of clinical trials conducted in the U.S., Australia, and Korea in 2008, tests were conducted on various types of cancer, but subsequently, expansion tests were conducted in the same countries with non-small-cell lung cancer as the subject at the recommended dose achieved in the phase I of the clinical trials.

At the American Society for Clinical Oncology 2010 conference held June 4 to 8, 2010, the results of clinical trials of crizotinib which had as its subjects 82 patients with non-small-cell lung cancer with *EML4-ALK* fusion gene in the U.S., Australia, and Korea were presented. Disease control rate of crizotinib was reported to be extremely high at 87%, adding together complete response (the drug was completely responded to), partial response (the drug was effective) and no change (the drug blocked the progression).[20] Reference[20] is the abstract of the presentation, and the actual presentation included additional patients and revised data.

Global Phase III of clinical trials has already started for crizotinib (scheduled for September 2009 to September 2012).[21] This Phase III of the clinical trials is aiming to evaluate the efficacy and safety of crizotinib by comparing the drug with standard chemotherapy agents (cytopathic drug pemetrexed or docetaxel). Countries conducting trials are the U.S., Australia, Bulgaria, Canada, Germany, Hong Kong, Hungary, Italy, Japan, Korea, Poland, Russia, Spain, and England, and within Japan, trials is scheduled to be conducted in Tokyo, Osaka, Aichi, Chiba, Hokkaido, Hyogo, Shizuoka, Okayama, and Fukuoka (as of July 10, 2010).

6 Future Research and Development in Japan and Around the World

Development of molecular target therapy for lung cancer started with the low molecular drug Iressa® targeting EGFR. Another low molecular drug targeting EGFR, Tarceva® and antibody drug Avastin® targeting VEGF are now used for lung cancer treatment. In addition, while the development of new molecular target drugs for lung cancer has undertaken, ALK tyrosine kinase inhibitor, which is currently undergoing clinical trials, should begin to be used in clinical practice in the near future. Though problems seen with Iressa® such as side effects and drug resistance should be resolved in the early stages, clinical selection of molecular target drugs for lung cancer is widening.

While the actual application of molecular target drugs for lung cancer is progressing, researchers around the world are making a great effort to find new target molecules and develop molecular target drugs. In the search of therapeutic target molecule for lung cancer, the Cancer Genome Atlas Project

(TCGA project), which started as a pilot project at the U.S. National Institutes of Health (NIH) in 2005, is receiving much attention. This project aims to identify the important genes responsible for lung cancer by screening the entire genome of cancer cells using squamous cell cancer of non-small-cell lung cancers and by evaluating the samples from patients (in their pilot project, they were targeting only 3 types of cancers: brain cancer, ovarian cancer, and lung cancer; however, the NIH reported that it would expand the targets to cover over 20 types of cancer in 2009).

While discovery of new therapeutic target molecules is anticipated from large-scale cancer genome analysis such as the TCGA project and currently ongoing projects, there has been an effort to expand the indication of molecular target drugs approved for treating other types of cancers to include lung cancer. Since there is an expansive range of basic and applied research as well as clinical trials, I have discussed the research by Dr. Mano et al. as a successful example. Dr. Mano et al. discovered the *EML4-ALK* fusion gene responsible for lung cancer by a focus formation assay, achieved by breaking through its limitations to isolate an organ-specific oncogenes. It is believed that this new technology will be extremely useful in the search for other oncogenes other than the *EMK4-ALK* fusion gene. The acceleration project, New Cancer Gene Identification Project by the Japan Science and Technology Agency (JST)'s Core Research for Evolutional Science and Technology (CREST) will use the methods developed by Dr. Mano et al. (scheduled for January 2009~March 2014).[22]

In order for molecular target therapy for lung cancer to progress, it is urgent for the mechanisms and risks of side effects of and drug resistance to currently used drugs to be analyzed and for preventative measures for the risk to be developed. In addition, continuous efforts should be made to find new therapeutic molecules for lung cancer and to develop drugs and diagnostic methods based on the molecular information. In addition to these scientific and technological tasks, issues of the medical system should be resolved as well. Taking the research of Dr. Mano et al. as an example, since its clinical value has already been accepted, molecular diagnosis using the *EML4-ALK* fusion gene should be made more clinically accessible by opening it up to insurance coverage like EGFR gene testing. Early discovery of cancer by *EML4-ALK* fusion gene diagnosis enables the early start of treatment, which subsequently reduces treatment costs. In addition, in such cases, the indication of molecular target theraphy should be set earlier than stage III to IV of lung cancer. Guidelines on lung cancer treatment should be reconstructed, and physicians should be clearly notified.

Cancer research in Japan has been conducted centering on the Comprehensive 10-year Strategy for Cancer Control (fiscal years 1984 to 1993), the New Comprehensive 10-year Strategy for Cancer Control (fiscal years 1994 to 2003), and the Third Comprehensive 10-year Strategy for Cancer Control (fiscal years 2004 to 2013).[23] From fiscal year 2011, cancer research is likely to progress even further with the general governmental action plan for science and technology policies. To achieve "life innovation," the important goal set by the New Growth Strategy (cabinet approved on June 18, 2010), the action plan aims to actualize a "physically and mentally healthy and vigorous" society and "independence for the elderly and handicapped" by 2020, and promotes three priority tasks.[24] One of the three is the "improvement of the cure rate" of cancer "through innovative development of diagnosis and treatment," and one of the directions to achieve this is the development of molecular target therapy. The development includes basic research such as "finding new targets by revealing the properties of cancer (proliferative inhibition, differentiation control, prevention of metastasis and cell death)," and extends to applied research as "research and development of drugs (low-molecular and antibody drugs)," showing that the development of molecular target theraphy will be promoted as a national strategy.

Acknowledgements

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I would like to thank Dr. Mano for his kind and numerous advice and reference materials.

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Profile

Hiromi OMOE
Life Science Unit
Science & Technology Research Center
Senior Researcher
http://www.nistep.go.jp/

Veterinarian, PhD in agriculture. Before assuming her current position, Dr. Omoe worked in molecular pathological research as it relates to disease in humans and animals. She is interested in science and technology policies to ensure safety in environmental factors such as food, microorganisms, and chemicals.

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2

Smart Grid as New Big Opportunity of Information and Communication Technology

Kazuyoshi HIDAKA
Affiliated Fellow

1 Introduction

The next generation power supply system, holding the promise of gaining higher reliability, lower cost, and reduction of load on the environment by utilizing Information and Communication Technologies (ICT), is often referred to as the Smart Grid. The smart grid may have a greater significance if viewed as an arena for the next stage of developments in ICT industries, providing a new social and economic infrastructure.

Major differences between the conventional electric power system and the smart grid are shown in Fig. 1.1,[3] The conventional electric power system consists of three components: generation (concentrated fire/water/atomic power generation), distribution (power transmission and distribution), and power consumption by the customers. The flow of electric power is unidirectional from upstream: generation, transmission, distribution, and then consumption. Advanced power systems, such as implemented in Japan, provide a flow of information, mainly used for detecting failures in the sections from generation to transmission.

The smart grid has additional system elements, e.g. distributed power sources that utilizes renewable energy such as solar power and wind-power generation, and stored power sources. On the customer side, they not only consume electricity, but also generate and store electricity using solar photovoltaics. New vehicles with electricity generation and storage functions, as well as electricity consumption, (such as the Plug-in Hybrid Electric Vehicle (PHEV)) will become involved in the distribution system. Two-way flow of electric power and information will take place among these constituent elements.

A still more importance change in the smart grid comes from electric appliances (e.g. air conditioners and refrigerators) and "electricity consuming artifacts" such as light fixtures: all of these will be connected to the network and constitute new elements that exchange information as along with consuming electricity.

In line with the global trend toward a low-carbon society, the effort to save energy has become a ubiquitous need in all areas of our activities including our personal lives, business operations, and local societies. The trend has also been giving support globally to accelerate research and development toward commercial realization of the smart grid. The reason underlying this trend is that, for social implementation of renewable energy sources (e.g. photovoltaic generation, wind-power generation) and sources expected to effect substantial reduction of CO_2 emission (i.e. PHEV), a high-level control system is needed to coordinate these new sources with conventional ones. In addition, further pursuit in saving energy requires visualization of electricity consumption, introduction of market mechanisms, and power supply control from the supply side, and all of these need higher-level control such as provided by the smart grid.

In the United States, where the power system is becoming decayed and outdated, introduction of the smart grid is an urgent necessity for enhanced reliability (electric outage prevention), promotion of demand control (saving energy), and introduction of distributed electric sources. Special emphasis here is placed on the demand control facilitated by the implementation of smart meters (see the discussion below). This approach is expected to have a substantial effect at a cost smaller than total renovation of the outdated distribution system,[4] and it also would contribute to the construction of a new social service infrastructure.

In Japan, not a few people have a skeptical view toward the U.S.-led way in which the smart grid implementation is promoted. One major reason for this is the fact that, in decisive contrast to the situation in the United States, Japan currently has a very stable power supply situation[6] and infrastructure supporting it. The move toward introduction of the smart grid in Japan is motivated by the desire to implement a management system that coordinates conventional power systems with the new array of next-generation environment/energy technologies such as photovoltaic power generation, wind-power generation and PHEV. Concerns on environmental issues, such as the reduction of CO_2 emission, are likely to add momentum toward a wider utilization of these technologies, but the subject of to what extent these motivations will affect the development of the "smart grid" is still controversial.

The original idea of the smart grid was to supply stable and environmentally-friendly electric power. It is quite understandable, therefore, that we often try to find the key to our future evolution in new electric power technologies and industries that are related – especially in conjunction with renewable energy and secondary batteries - to electric power generation, transmission, and power storage. This is not an erroneous view, but we should not overlook the potential expansivity of the areas that seem to be a subsidiary to the main stream. That is, let us not lose sight of the potentiality that a much scaled-up version of a communication network – many-fold greater in scale than the current Internet – is expected to emerge, having a huge impact on the technological and industrial aspects of our society in the future.

Especially in the United States, the move toward the smart grid has been gaining great momentum both in the government and industrial sectors. A group of leading companies in the ICT industry – Google, AT&T, Cisco, Oracle, and IBM – has entered into the technical development and business in this field. The current situation indicates that the economic circle in the United States sees this field as a coming important market for the ITC industry.

The smart meter, slated to be installed in households in coming years to bring the smart grid to practical use, will likely serve the role of an interface for connecting a variety of electric appliances and sensors to the external communication network, leading these "electricity consuming artifacts" in each household more and more into the arena of Internet connectivity, in addition to the heretofore actor, i.e. "people." As

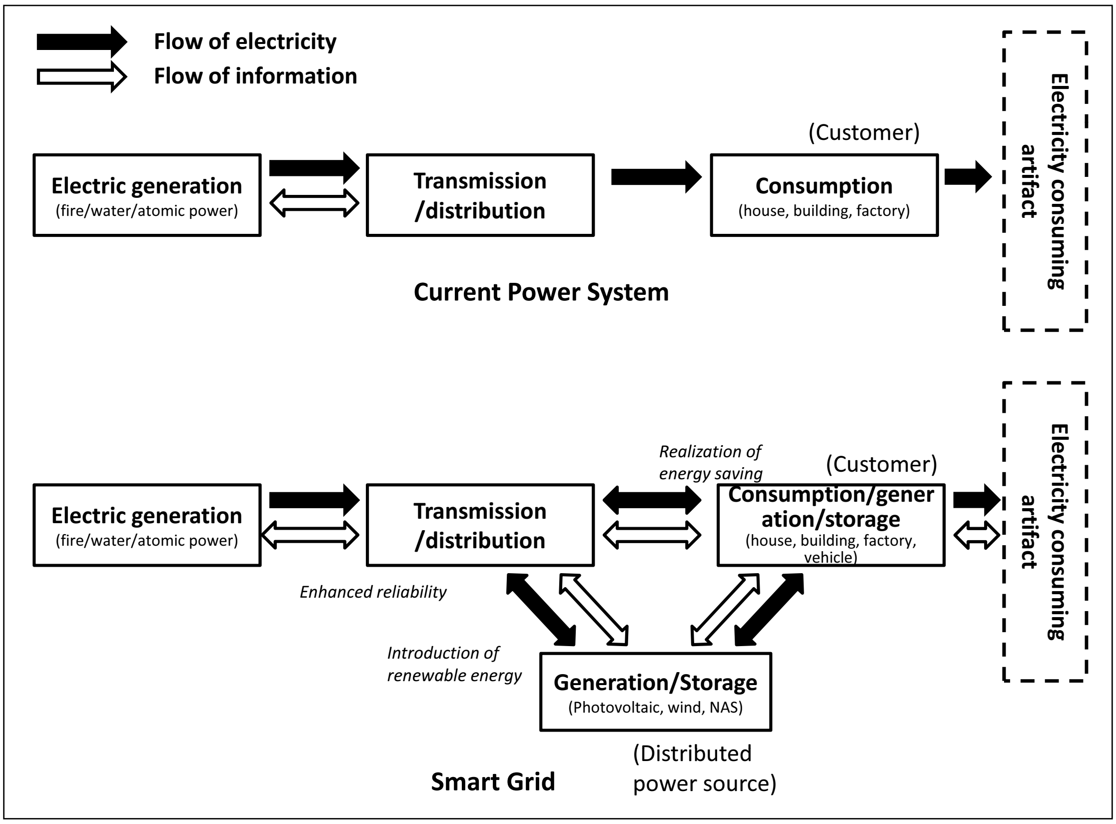

Figure 1 : Smart System vs. Current System

Prepared by STFC based on Reference[1,3] exemplified by the high expectation that "replacement of all 2.7 billion domestic power meters with smart meters will create a huge market for the semiconductor manufacturers,"[4] it is important to understand that it will spur the growth of a huge ICT market for semiconductor and communication equipment manufacturers, as well as for the software and related services used in these devices and instrument.

This report covers current developments of the smart grid from the perspective of ICT.

2 Global ICT Related Smart Grid Market

The global size of the ICT-related smart grid market is around 89 billion USD (about ¥9 trillion) as of 2010, and is forecast to continue a 20% growth rate into a size of 170 billion USD (about ¥17 trillion) in 2014 (Fig. 2: a document from Zpryme research & consulting). Market size analysis of smart grid related element technologies forecasts 18% yearly growth in the sensor and device sector, 21% in the IT software and hardware (computer) sector –used to administrate/

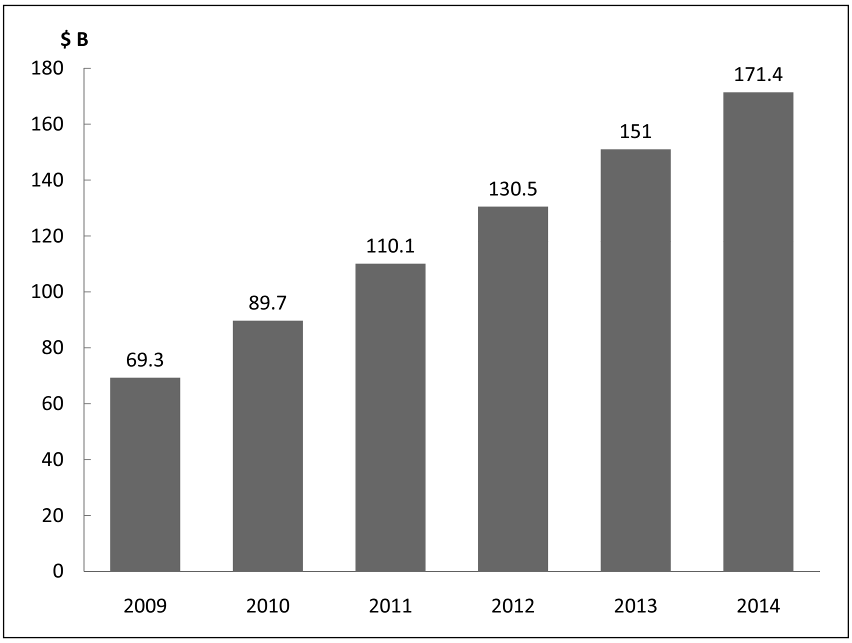

Figure 2 : Global Market Forecast: Smart Grid Related ICT

Prepared by STFC based on Reference[19]

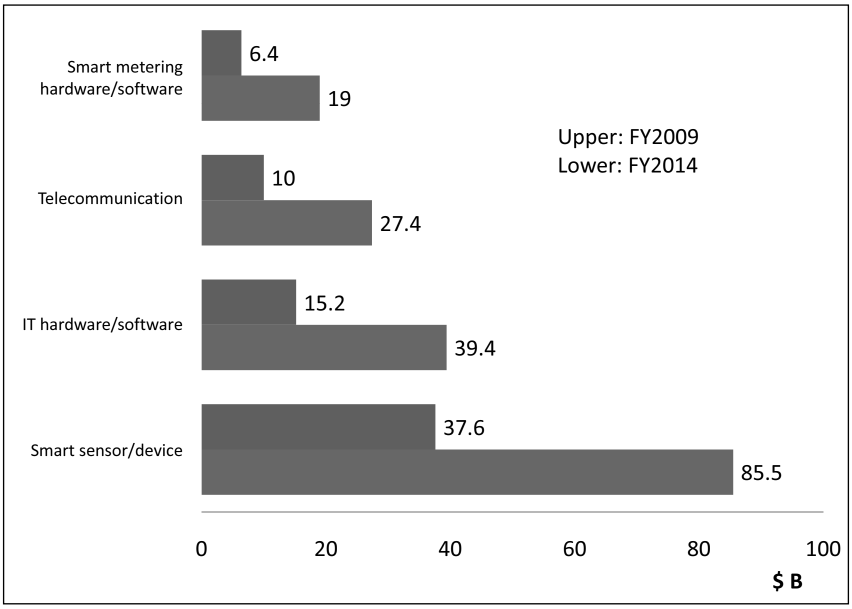

Figure 3 : Global Market Forecast: Smart Grid Related ICT (Sector by Sector)

Prepared by STFC based on Reference[19]

control the entire system, 22% in the communication related sector, and 24% in smart meters. The first three sectors combined - sensor and device, IT software and hardware (computer) to manage/control the entire system, and communication – make up 89% of the entire smart grid related market. In view of the economic situation in recent years and the fact that there is scarcely any sector capable of achieving 20% yearly growth, the smart grid and related ICT sectors represent a growth market of primary importance.

The number of smart meters on a global installation base will grow from 7.6 million in 2009 to 210 million in 2014.[3] The penetration rate of the smart meter is estimated to reach 18% globally in 2015, and in North America, the rate is forecast to grow from the current 5% up to 55%.[3]

3 Trends in the United States and Japan

3-1 Trends in the United States

3-1-1 Scale of Government Investment and its Estimated Effect

In the United States, investment in smart grid related fields is quite active centered on modernization of the power system led by the diffusion of smart meters.

The federal government has invested 4.5 billion USD in the smart grid accompanied by the enforcement, in 2009, of the American Recovery and Reinvestment Act (ARRA).

Out of this investment, 3.4 billion USD is allotted to the ground programs, which serves to build facility infrastructure for enhancing the reliability of the power network and promotion of demand control. Under the plan, this investment has an effect of introducing smart meters to 40 million households, roughly one-third of all households in the United States.

Aside from this, 6.2 billion USD is allotted to regional demonstration programs and energy storage demonstration programs, where introduction of distributed power sources plays a central role.[3]

The effect obtained from these 3.4 billion and 6.2 billion USD investments is estimated as follows:[3]

- Lowers the frequency of electric outages, reducing loss by 150 billion USD in a year (500 USD per capita)
- Reduces peak demand by 1400MW or more (capital cost 1.5 billion USD) and lowers the power charge
- Makes the grand objective attainable (i.e. 20% of energy will be supplied from renewable sources)
- Creates jobs for several tens of thousands of workers
- Induces 4.7 billion USD of investment from private sectors

3-1-2 Coalition among Utility and ICT Companies, Universities, and Public Research Organizations

Table 1 shows the list of major projects to be undertaken in line with the grand program.

Utility companies, in coordination with major players in the IT industry, are approaching projects in such areas as dynamic management, price setting, automation, surveillance, and network management. The venues for implementation and tests for these projects are provided mainly by schools and universities. For example, the project carried out by Florida Power & Light Company aims at, using smart meters, developing a more stable and intelligent power supply, and a test will be performed on the photovoltaic generation platforms installed in universities and schools. Three hundred units of PHEV will be introduced to universities (Miami Dade College, Florida International University, and the University of Miami) on a trial basis, and around fifty charging stations will be installed to support them. Other development objectives include: household energy displays, power saving devices for automatic selection of low-consumption mode at the time of peak demand, programmable thermostats controlled by a smart meter, and demand management and demand-response software to control household appliances and lighting fixtures. These development efforts will be carried out in cooperation with IT companies.[22]

Table 2 shows the list of major projects carried out based on the regional feasibility program. Coordinated groups of utility companies, ICT companies, universities, and public research organizations are approaching specific demonstration themes, where a special focus is placed on gathering basic data supposed to have increased importance in the future - relation between human activities and energy usage, and cyber security. For example, the demonstration project of Los Angeles Water and Electricity Bureau selected a university campus as the site of regional infrastructure feasibility studies, the results of which may be applied to commercial, medical, retailer, and industrial areas. In this project, the plan also includes advanced research and development in the broad context of information technology, as well as that directly related to information equipment such as: a comprehensive analysis of human activities and energy usage as affected by the construction of information infrastructure, a feasibility study of the next generation server security technology, and usage pattern analysis of electric vehicles operated by users without charging equipment.[23]

3-1-3 Active Moves of ICT Companies

In addition to the familiar players in the electric power management market such as GE, IBM, and Accenture, a growing band of IT companies is trying to enter into this market, targeted at general consumers. Take, for example, that AT&T aims at expansion of wireless networks, Cisco Smart Grid Solution supports household IP networks, Cisco is geared toward establishing building energy management infrastructure, Oracle is trying to open energy management systems to general consumers, Google takes sight of household energy management (Google Power Meter) and other emerging businesses in this line, and Microsoft is developing a household energy consumption management system taking advantage of cloud computing.[2]

Some information companies are trying to take equipment directly related to power monitoring into

Table 1 : Major Granted Programs

Utility Company	Federal grant, State granted, Number of smart meters	Target	IT company
Central Point Energy	200 mil. USD. Texas, 220 mil.	More than 550 sensors, automatic switch	IBM, GE, Itron QuantaServices
Baltimore Gas & Electric	200 mil. USD. Maryland, 110 mil.	Expanding program capability for dynamic charge setting and direct load control.	(N/A)
Duke Energy Business Services	200 mil. USD. North Carolina, 140 mil	Dynamic charging program, two-way communication, advanced automatic distribution applications, PHV	Cisco, Echelon
Florida Power & Light Company	200 mil. USD. Florida, 260 mil	9,000 intelligent distribution equipments and advanced monitoring equipments.	GE, Cisco, Sliver Spring, SunPower
Progress Energy Services	200 mil. USD. North Carolina, 16 mil.		IMB,Telvent

Prepared by SFTC based on Reference[3]

Table 2 : Major Projects Included in the Regional Demonstrative Program

Demonstrative Project	Government grant Target region	Content	Utility company	University, IT enterprises, and others
Northeast Pacific Coast Demonstrative Project	88 mil. USD Washington	・Two-way communication (dispersed sources, secondary battery, source of demand, existing grid) ・Implementation of SG cost-gain calculation ・Interconnectivity, security	Twelve utility companies in Battle Memorial Institute region.	University: UW, WSU Enterprise:IBM, 3tiers, Netzza, QualityLogics
Ohio Grid Smart demonstrative project	75 mil. USD Ohio	・Demonstration of 13 technologies (automated distribution, smart meter equipment, Home Area Network (HAN), PHEV, storage, renewable energy, etc.)	Columbus Southern Power Company	Research Institute: EPRI, PNNL Enterprise: Battele, GE, Silver Spring, Lockheed Martin
Los Angeles Water and Electricity Bureau regional demonstrative project	60 mil. USD California	・Demonstration within premises of universities ・Energy usage of general consumers, cyber security technology, and integration with PHV.	Los Angels Department of Water & Power	University: USC, USLA, CalTech
Demonstration of open grid with safety and interconnectivity	45 mil. USD New York	・Security, peak demand reduction, enhanced reliability (renewable energy, grid monitoring, EV, automated transmission, consumer system)	Consolidated Edison Company of NY	University: EPRI, Columbia Enterprise: Boeing, Prosser, CALM Energy
Irvine demonstrative project	40 mil. USD California	・From transmission/distribution system to smart devices. ・Focus on interconnectivity and security	Southern California Edison (SCE), PG&E	University: USC, EPRI Enterprise: CE, Cisco, IBM, Boeing

Prepared by SFTC based on Reference[3]

their own businesses. For example, IBM provides a solution utilizing a smart meter, or a household power meter with an embedded two-way communication function and PC capabilities (Fig. 4). The provision of this solution is a part of its strategy to construct the Intelligent Utility Network (IUN), which serves as a transmission and distribution system with enhanced efficiency.[7]

Google, on the other hand, developed a suite of software called Google PowerMeter and distributes it through the Internet. This software allows access by way of Internet browsers. The PowerMeter allows obtaining power consumption information from the contracted utility company for easy monitoring at home and in the office. Visualized monitoring of electricity consumption is expected to have an effect toward saving energy. The software also enables the consumer to obtain information, through the network, from a clip-on power meter that allows installation on a distribution board.

3-1-4 Emergences of New High-Tech Companies

In the United States, it is also to be noted that a new breed of advanced companies, different from those described in the previous section, is emerging aiming at the new businesses that have evolved accompanying the smart grid. These include new starters as well as emergences from different fields. For example, Silver String Network, Itron, and Landis+Gry provide demand side equipment used in Advanced Metering Infrastructure, Comverge and EnerNoc provide demand-response instruments, and GridPoint provides equipment related to household networks.[9] Many of these started business around 2000 or later, mainly in the field of meter-related equipment manufacturing, and are geared to cultivate a new smart grid business by linking their products to the network. As seen from Table 3, these companies have steadily or dramatically expanded their sizes and sales.

For example, Silver Spring Network, a spin-out venture from Google, was established in 2002 and now has a workforce of about 200 employees,[9] and it has already gained major utility enterprises as customers in and outside of the United States. The customers include American Electric Power, CitiPower&Powercor Australia, Florida Power & Light, Jemena, Modesto Irrigation District, OG&E Electric Services, Pacific Gas and Electric Company, Pepco Holdings, Sacramento Municipal Utility District, Powerful, and Influential Leadership.[10] In the background of the growth of Silver Spring Network lies the company's policy to embrace all aspects of the business (i.e. providing solutions and services as well as products), and its success in establishing collaborative relationships with various companies in diverse fields (demand-response, distributed power sources, electric vehicles, home networks, communication, and software) seems also to have given the company an edge (see Table 4).

GE, accompanied by four venture capital corporations, unveiled its plan to set up a fund of 200 million USD to promote the development of smart grid related new technologies.[24] Such a fund could induce further new entries and encourage new businesses.

3-1-5 Standardization and Legislative Preparation

The basic idea underlying the smart grid technology development in the United States is to secure interoperability.

The Internet represents, just as the word consists of "inter" and "net," a network that provides interconnection among networks. By the same token, the basic idea of the smart grid is to provide a "grid between grids," or a grid connecting various types of grids.

If there were standardization work to be done by the state for the realization of the smart grid, it would be the establishment of a protocol for securing grid-to-grid interconnectivity. In the United States, this

Figure 4 : A Smart Meter from IBM[7]

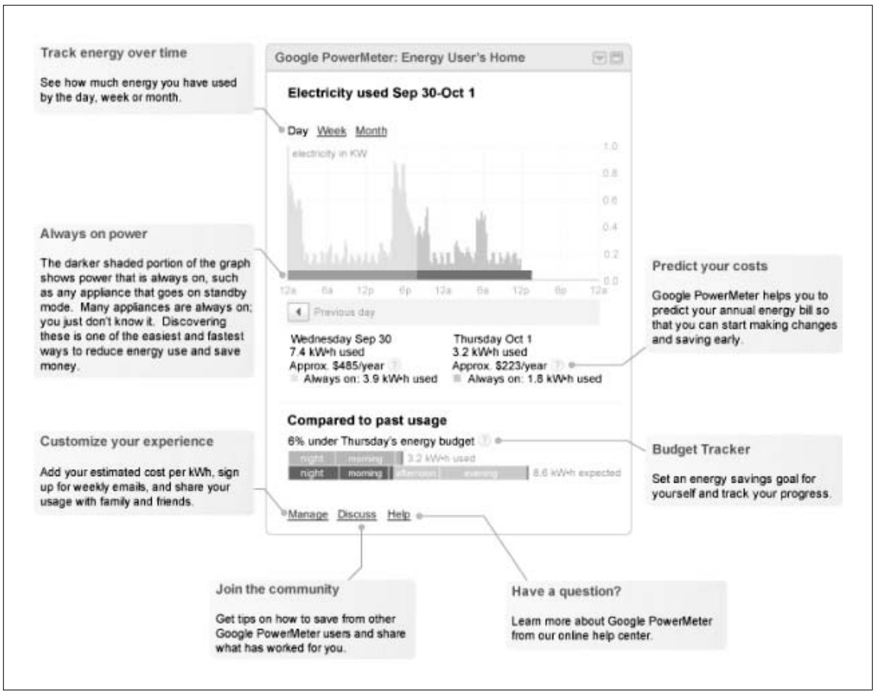

Figure 5 : A Screen Display from Google PowerMeter[8]

Table 3 : New Entries into The Smart Grid Related Fields

Enterprise	Home city	Established	Overview
Itron	Liberty Lake, WA	1977	･Released the first product in Idaho in 1977 ･Acquisition of Schlumberger Advanced Metering (2004) and Actaris (2007) ･Customers include more than 8,000 utility companies. AMR*, AMI** etc. ･Sales: 664 (2006), 1,464 (2007), 1,910 (2008) (mil. USD). Payroll ≥ 8,500.
Landis + Gyr	Switz.	1886	･Purchased by an Austrarian investing company in 2004. ･Has sold more than 300 million meters. ･Sales: 1,364 mil. USD. Payroll: 5,070.
Sensus	Raleigh, NC	2003	･Established in the late 19th century as a meter manufacturer in Pittsburg. Assumed current trade name after undergoing several acquisitons (by Rockwell and others). ･AMR*, AMI**, etc. Payroll: 3838. Sales: 633 (2006), 694 (2007), 671 (2008) (mil. USD).
EnerNOC	Boston, MA	2001	･Customers include 1,650 commerce/industrial businesses. Supplies up to 2050MW of electricity. ･Sales increasing: 26 (2007), 61 (2007), 106 (2008) (mil. USD).
Echelon	San Jose, CA	1988	･Provides Networked Energy System. ･Payroll: 325. Sales: 137 (2007), 134 (2008) (mil. USD)
Comverge	East Hanover, NJ	1997	･Established by a merger between PowerCom and a Lucent business unit (1997). Acquired a business unit of Scientific Atlanta (1999) and Sixth Dimension (2003). IPO in 2007. ･Has sold more than five million units of equipment. SDGE (CA), Public Services Company of New Mexico, PacifiCorp, New England ISO etc. ･Sales: 34 (2006), 55 (2007), 77 (2008) (mil. USD).
Ambient	Newton, MA	1996	･Internet based smart grid (AMR* inclusive). ･Sales: 2.3 (2006), 12.6 (2008) (mil. USD). Payroll: 38.
Silver Spring Networks	Redwood City, CA	2002	･Internet based AMI** and demand handling. ･Major customers: Florida Power & Light, PE, Pepco, Jemena, Electricity Networks, and United Energy Distribution.
Trilliant Networks	Redwood City, CA	2004	･Predecessor established in 1985. Current business started in 2004. ･AMI**. Has distributed more than a million meters. Customers include more than 200 electric power businesses.

Prepared by SFTC based on Reference[2]

Table 4 : New Entries into The Smart Grid Related Fields

Technology	Cooperative firms
Advanced Metering	Elster, GE Energy, Itron, Kinects Solutions, Landis + Gyr, Nansen, PRI
Demand Response / Energy Management	Comverge, EnerNOC
Distribution Automation	ABB, DC Systems, S&C Electric Company
Electric Vehicles	ClipperCreek
Home Area Networks and Devices	Arch Rock, Carrier Corporation, Control4, Energate, Exegin, Invensys, LS Research, Onzo, Radio Thermostat of America, Tendril
Networking	Cisco, Digi International, Sierra Wireless
Software	eMeter, Freestyle Technology, GEEnergy, GridPoint, Itron, OSIsoft, Oracle

Prepared by SFTC based on Reference[10]

standardization work is being undertaken by the National Institute of Standards and Technology (NIST), an organization under the Department of Commerce. The standardization work will, in the future, guarantee interconnectivity among the advanced technology grids with different origins, thus allowing independent development efforts.

In line with the stipulations of the Energy Independence and Security Act (EISA) established in 2007, the U.S. federal government invested a 500 million USD budget into NIST for the development of standards to secure total operation of the smart grid in terms of ICT, and maintenance of security. As aptly described in the notes of a NIST report – "protocols and standards for information management for interoperability of smart grid devices and systems" – the work places a focus on standardization for information exchange. In the background of these standardization activities lies, according to some reports, an implicated strategy – "The Obama administration has a strategy to eventually gain global supremacy on the smart grid market, by first investing massively in this field for the development and commercialization of related technologies, and to push up the level of U.S. companies in this field."4] In the United States, a bill stipulating mandatory provision of real-time smart meter information to customers was introduced to Congress11], indicating that legislative preparations are also under way to activate smart grid operation.

3-2 Trends in Japan

Several demonstrative projects have already begun in Japan as well. These include: a smart grid experiment using 3,000 power meters undertaken by Kansai Electric Power Co. Inc., Demonstrative new system energy introduction project for isolated islands undertaken by Okinawa Electric Power Company, Incorporated,[12] a smart grid demonstrative experiment in Rokkasho village that introduces wind-power,[13] and a demonstrative experiment for the optimization of a next generation transmission/ distribution system[14] – a joint project participated in by Tokyo University, Tokyo Institute of Technology, and many electricity enterprises.

The new Energy and Industrial Technology Development Organization (NEDO) has organized a smart grid demonstrative experiment under the initiative of Japanese enterprises in New Mexico in the United States. Various legislative controls in Japan often make technological experiments difficult, but these can be carried out relatively free of constrains in the United States. In the background of the project also lie such factors as: the state of New Mexico has differentiation from other states in mind by introducing Japanese companies' technology, and New Mexico is especially suited for photovoltaic power generation experiments due to it having the highest level of insolation among all states. Note, however, that this project is heavily concentrated on experiments related to photovoltaic and secondary battery technologies, thus information technology is not one of its major concerns.

The Next Generation Energy and Social System Council – a cross-sectoral project team in the Ministry of Economy, Trade and Industry (METI) – has decided to carry out a domestic experimental implementation of a "smart community" aiming at creating the next generation urban area utilizing innovative ICT, energy, and traffic systems. In concrete terms, Yokohama city (Kanagawa pref.), Toyota city (Aichi pref.), Keihanna science city (Kyoto pref.), and Kitakyushu city (Fukuoka pref.) have been selected as the sites for this project.

In another development, the "smart community forum" – a forum for gathering and discussion between the smart grid and smart community related enterprises under the secretariat of METI – was inaugurated in 2009. The ideas underlying this forum are: pursuit of action possibilities undertaken by the demand side, sharing of a smart community vision as it ought to be, clarification of the proper system architecture and individual elements, and establishment of alliances and strategies for overseas deployment as a system.[15] As one outcome of this forum, the "smart community alliance" was established, in June 2010, based on 352 impeller enterprises, under the secretariat of Endowing, and in line with the concept of this alliance, working groups for international strategy, international standardization and roadmaps for smart houses have started their activities.

The Japanese cabinet approved the New Growth Strategy in June 2010. The "green innovation" project – one of the priority areas of the strategy – endorses realization of the smart grid.

In and around the 1990s, Japan had a project called OpenPLANET, undertaken by Shikoku Electric Power Co., Inc, which did not gain widespread momentum. The lack of success is ascribed to the following reasons: communication infrastructure in those times – such as power line communication (PLC) and PHS – was still in an immature state, and there was no way to propose such new household services that benefited from CPU-installed power meters.[16] As illustrated by this example, the success of the project seems to depend largely on the proposal of "killer applications."

4 ICT in Smart Grid

4-1 The Role of ICT

Figure 6 illustrates the role of ICT in the smart grid. The following research and development have already been under way and have attained a certain level of realization: a supervising system for power generation, supply and demand control system for optimum power generation, coordinated system surveillance/control and an automatic distribution system for stable power transmission and distribution. Meter-reading has already been automated in part. As described earlier, the smart grid provides power generation and storage functions additionally to the demand side. Introduction of these dispersed power sources will make the entire system drastically more complex and will require a much higher level of system control. In addition to the functions provided by conventional ICT, a higher level of data collection, transmission, storage and processing will be required to cope with the enormous information flow incoming from generators, transmission/distribution systems, and distributed power sources. Functionality for surveillance, control, and support for decision-making based on the flow of information will also be required. The smart grid will also call for new technological developments for the demand side – typically the Advanced Metering Infrastructure (AMI), where Building Energy Management System (BEMS) and Home Energy Management System (HEMS) play a central role.

Examples of ICT introduction to electric power systems in Japan include the case where Tokyo Electric Power Company embedded a communication function in almost all of the power lines upon installation, enabling hazard detection both in the backbone and distribution networks. As a result, the yearly average of blackout time per household in Japan has been reduced down to 16 minutes, proving the superior effect of the control system construction (See Fig.7).

Advanced use of the control system will be required for the introduction of renewable energy to each region and household. As supply and demand must always be balanced in an electric power system, conventional power systems have the ability to boost output in quick response to an increase in demand. Renewable energy sources (e.g. photovoltaic generation, wind-power generation) depend largely on the weather, resulting in fluctuation of power output. An advanced power system is required for the existing power systems to accommodate the power fluctuation. In Japan, METI announced the introduction plan of photovoltaic power generation of as much as 53GW by 2030, but the Federation of Electric Power Companies – a joint council of ten power utilities – estimated the upper limit as 10GW. The reason underlying this upper limit is the fact that photovoltaic power output fluctuates substantially, having a serious effect on the operating quality of the system. Introduction of a management system based on the smart grid is expected to alleviate this deleterious effect.[3]

In the United States, research and development investment on the management system, for coordinating the power system with local/home networks, has been gaining momentum. In view of the situation that the introduction of renewable energy into social networks will still take a while, industrial sectors are giving priority to home networks as the platform for technological development and social implementation.[3] The management system is realized by implementing Advanced Metering Infrastructure (AMI) – a monitoring/control system for demand side instruments, which consists of management systems for smart meters, home appliances, and communication, and the Home Energy Management System (HEMS). The component of special importance in the system is the smart meter, or the power meter with communication capabilities for data input from and control over the household appliances. Addition of a wireless communication function to the conventional power meter provides connectivity with household appliances (e.g. air conditioners, lighting fixtures) and sensors such as thermometers, enabling it to collect information such as power consumption and temperature. As the smart meter is also connected to the external network, all household appliances, sensors and power meters in the world become communicating agents of the Internet via the networks.

One of the merits of introducing a smart meter into

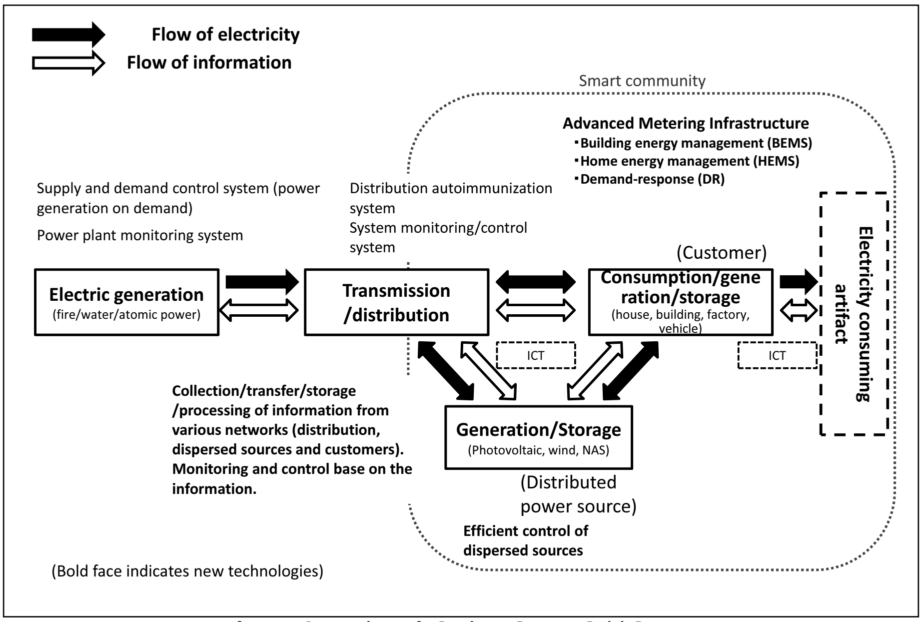

Figure 6 : Roles of ICT in a Smart Grid System

Prepared by SFTC based on Reference[1,3]

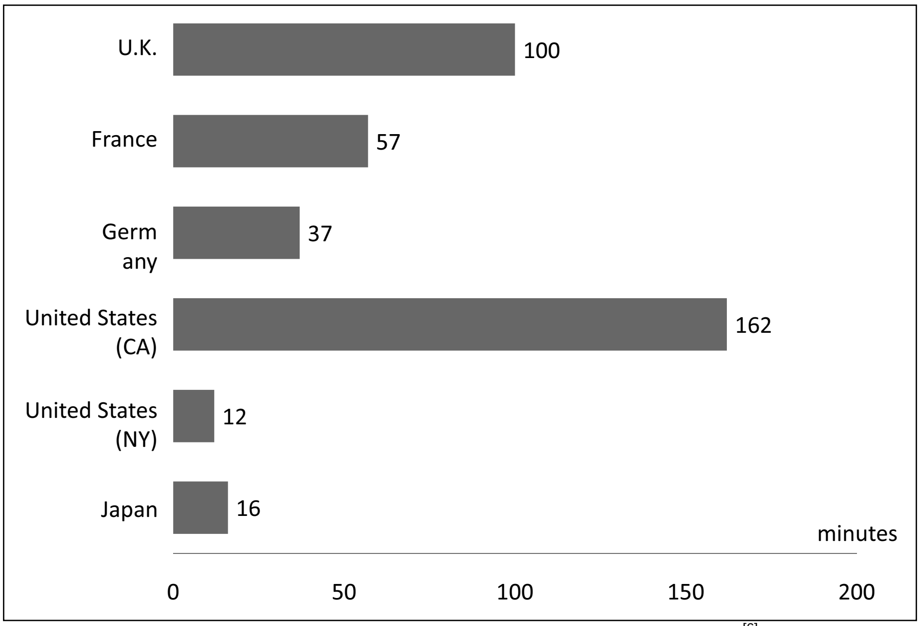

Figure 7 : Yearly Blackout Hours in Major Countries (See Reference[6] for the year)

Prepared by SFTC based on Reference[6]

a household is visualization of power consumption status, promoting a spontaneous power-saving attitude in every household. Monitoring of electric appliances and implementation of an on/off control function enable the demand side to have the management capability for more efficient power usage. In addition, the supply side (utility companies) will be able to exercise forced supply control at the time of peak demand. In the future, when photovoltaic generation becomes a common practice in every household, and trade of redundant electric power becomes widely available through, for example, the introduction of PHEV, the smart meter is expected to play an important role as an access point to guarantee stability of the power market, which is dynamically driven based on market principles. It is also probable that an array of new businesses will be created by grasping lifestyles based on the detailed power usage information provided by the household. However, privacy protection will remain an important issue in this future society.

4-2 Emergence of a Giant Network

In the future, millions of smart meters, water heaters, household appliances and a vast number of sensors will be connected to the existing social infrastructures (i.e. the power system, renewable energy system, gas supply system and water supply system), causing the emergence of a far-flung, global network much larger in size than the current Internet. When this situation becomes a reality, robust networks and advanced information processing systems are required to collect and analyze the vast amount of data from the connected devices for controlling them. Underlying these networks, architectures and information security technology will play a critical role for interconnecting various types of dissimilar nodes.

In contrast to the Internet as we know it today, where only abstracted trains of bits (0101…) are transmitted, newly emerging networks transmit physical entities as well, causing a substantial increase in the complexity of the networks. In the newly emerging networks, just as is the case with the current Internet, such functions as collection, transfer, storage, processing, search, and presentation of data, security, and protection of privacy will be required.

4-3 Elements of ICT Underlying the Smart Grid, and Their Standardization

Table 5 shows a list of element technologies underpinning the smart grid (compiled by the United States Department of Energy).

In this classification, importance is placed on two-way communication technology to make the smart grid an efficient and reliable real-time system. A two-way communication architecture - based on the concept of Plug-and-Play that guarantees expandability and ease of modification - must be established to realize mutual compatibility. Next comes the need for control technology supported by state-of-the-art algorithms, used for handling the vast amount of information incoming from smart meters and intelligent home appliances, and for control/diagnostics/price setting and resource management. Emphasis is also placed on the interface and decision-making support system that enable efficient and accurate operation, as well as the sensor and measurement technology.

In terms of two-way communication, drastic upgrade of short-distance wireless communication technology and its widespread implementation are expected. This includes such technologies as ad-hoc networks, mesh networks, and sensor networks that support multi-hop communication and networking household appliances. The development of distributed control systems is also a must for controlling them. As an example, ZigBee (a short-range wireless communication standard based on IEEE 802.15.4,) is receiving attention for monitoring and controlling the networks because of its capability to construct multi-mesh networks and lower power consumption than WiFi and Bluetooth. The ZigBee Smart Energy Profile specification has been set out in recent years, which stipulates the method for reading a meter, controlling instruments, real-time calculation of electric charges, transmitting text messages, data encryption, and unit authentication.[2,20] In addition, to facilitate the move toward the smart grid, a communication standard, Smart Utility Network (SUN), has been established as a part of standardization efforts around IEEE 802.15.4g. IEEE 802.15.4g is expected to be the wireless network standard in the age of the smart grid: it allows consolidating information collected from multiple home networks (within a radius of several hundred meters to several kilometers) into an information gathering facility of utility (electricity and gas) companies, and also enables two-way control.[21]

It is very likely that a variety of smart appliances (household appliances with ICT capabilities) will be developed in the future. The standard that stipulates the interface for connecting a smart appliance and a smart meter already exists, i.e. OpenHAN. Much of the standardization efforts for OpenHAN have been undertaken by major electric power businesses such as Pacific Gas & Electric Co. (PE&E) and South California Edison Co. (SCE), and American Electric Power.[2]

4-4 Issues Concerning the Smart Grid in Japan: A view from ICT

The Smart Community Forum, held under the auspices of METI, summarized the issues around the smart grid as viewed from ICT as described below, and made them public in June 2010.[15] In Japan, although there have been discussions toward realization of smart communities, research and development investment has been focused mainly on renewable energy (e.g. solar power) and secondary cells. Efforts toward enhanced research, development, and commercialization of ICT around the smart grid have not been sufficiently activated nor have they taken a concrete shape yet.

(1) Information System Architecture

The information system architecture must be so designed that it an optimized connectivity within and outside the home network, paying due attention to the roles played by the smart meter and home server. There must be a thorough discussion as to which of the two - the home server (computer) and the smart meter – is more desirable, or both hand in hand, to serve as the home gateway connecting all of the household instruments. The choice is important, because it determines whether a utility firm or the home server provider (communication company, home appliance manufacturer, housing manufacturer, ICT service provider, and other energy related businesses) carries out the task of collecting power usage information and controlling household instruments.

It is critical for the architecture to provide sufficient compatibility between openness and reliability of the home network. Openness of the interface is required for the home appliance network so that it will not, for the convenience of the user, tend to be a manufacturer specific interface. On the other hand, it must impose a certain level of discipline on connected devices (e.g. authentication) to maintain reliability. Therefore, the architecture must provide a balance.

Table 5 : U.S. Department of Commerce Counts On The Following Element Technologies for Establishing Smart Grid

Technology	Examples
integrated two-way communication Two-way communication makes the Smart Grid a dynamic, interactive, real-time infrastructure.	・An open architecture creates a plug-and-play environment that securely networks grid components and operators, enabling them to talk, listen and interact.
advanced components Advanced components play an active role in determining the electrical behavior of the grid, applying the latest research in materials, superconductivity, energy storage, power electronics and microelectronics to produce higher power densities, greater reliability and power quality.	・*Next-generation FACTS/PQ (power quality) devices* ・*Advanced distributed generation and energy storage* ・*Plug-in hybrid electric vehicles (PHEVs)* ・*Fault current limiters* ・*Superconducting transmission cables* ・*Microgrids* ・*Advanced switches and conductors* ・*Solid-state transformers*
advanced control methods Advanced control methods monitor power system components, enabling rapid diagnosis and timely, appropriate responses to any event. They also support market pricing, enhance asset management and efficient operations, and involve a broad application of computer-based algorithms.	・*Data collection and monitoring of all essential grid components* ・*Data analysis to diagnose and provide solutions from both deterministic and predictive perspectives* ・*"Diagnosis" and subsequent appropriate action processed autonomously or through operators (depending on timing and complexity)* ・*Provision of information and solutions to human operators* ・*Integration with enterprise-wide processes and technologies*
sensing and measurement technologies Sensing and measurement technologies enhance power system measurements and facilitate the transformation of data into information to evaluate the health of equipment, support advanced protective relaying, enable consumer choice and help relieve congestion.	・*Smart meters* ・*Ubiquitous system operating parameters* ・*Asset condition monitors* ・*Wide-area monitoring systems (WAMS)* ・*Advanced system protection* ・*Dynamic rating of transmission lines*
improved interfaces and decision support Improved interfaces and decision support will enable grid operators and managers to make more accurate and timely decisions at all levels of the grid, including the consumer level, while enabling more advanced operator training. Improved interfaces will better relay and display real-time data to facilitate:	・*Data reduction* ・*Visualization* ・*Speed of comprehension* ・*Decision support* ・*System operator training*

Prepared by SFTC based on Reference[17]

The following factors, in concrete terms, will be required: standardization and openness of home server APIs, standardization of home server middleware, and standardization of communication interfaces for connectivity with household appliances.

In terms of connection between an external and a home network, the communication scheme for network construction has to be determined. Eligible candidates include power line communication (PLC), wireless communication (3G/LTE, WiMAX, PHS, multi-hop communication), and wired communication (optical fiber ADLS, cable television). Who incurs the cost of network construction and how to guarantee security pose another issue. Regarding this connection, a decision has to be made as to the transmission scheme by which the network is constructed. The options for this decision are: an indiscriminate transmission scheme (or Internet scheme) with a cost advantage, and a specific application priority scheme (guaranteed transmission scheme) with higher reliability.

(2) Creation of New Services That Utilize Availability of Household Information

Availability of visualizable household energy information is expected to promote the creation of new services, for example, that make the user more energy-saving conscious by presenting visualized energy information. Other examples include the creation of optimum energy management services, where feedback information from power usage monitoring is used for effective use of renewable energy and expulsion of adverse effects on the system, or local management of the charging schedule for electric vehicles is utilized to optimize energy management and guarantees successful changing service within a given system capacity.

Other candidates of new services include: whereabouts/failure detection and remote repairing/maintenance of household appliances, information sourcing for the development of new products, on-demand home delivery service, and utilization of television sets as a household gateway monitor (provision of administrative information and on-line administrative procedures, TV conferencing for teleworkers, and information exchange among neighborhood residents).

(3) Establishment of Rules for Gathering/Managing/Utilizing Household Information

On the flip side of the various beneficial effects, there can surface an array of problems such as that the need for establishing rules that govern the activities to gather/manage/utilize household information (sensitive personal information may be contained) has been pointed out. It is considered appropriate that the following items are included in these rules: explicit indication of the intended purpose and use of data, and the name and substance of the agent that collects data, obligatory feedback of household information to the user, secured information portability, conditions to allow access to the home gateway, security requirements for networks and home gateways, and conditions to prevent information leak and illegal access.

(4) Other suggestions

Many other suggestions and opinions were put forward and discussed by the members of the Smart Community Forum. Among these, ICT related subjects are summarized, based on the reference material,[15] in Table 6.

5 Predictable Future

5-1 Global Competitiveness of Smart Grid Related ICT Industries

As I reported above, the smart grid is expected to provide a huge growth field for ICT industries. Especially from the viewpoint of ICT, however, the efforts toward research, development, and commercialization in Japan have not yet been brought well into shape.

Figure 8 shows schematically the differences in future international deployment strategy between the United States and Japan, as viewed from investment activities in technological development. The area of technological development can be broadly classified into three sectors: conventional power generation and transmission, renewable energy, and ICT. In the figure, the darker the color of the item, the higher the stage of development, and the lighter, the less developed.

In the United States, investment pervades every sector of industry. This will likely promote, in the United States, the evolution of systems with expandability and mutual compatibility in the near future, where coalition among ICT, renewable energy

Table 6 : Issues discussed in the Smart Community Forum

1) The need for investigation on economic efficiency and the mechanism of cost sharing
2) The importance of priority definition: domestic and overseas deployment requires different models and strategies
3) For overseas deployment, localized strategy is important, taking into account the local needs (including climate and cultural background)
4) A view toward creation of new businesses should be included: preoccupation with the discussion of energy supply and demand will not be enough.
5) The importance of maintaining balance between human control and utilization of natural force
6) The importance of open/black-box strategy: the key to the success of overseas deployment
7) The importance of total smart grid design for proper coordination between the distribution system and trunk power transmission system
8) The importance of investigation as to how Japanese element technologies will be fit into the unstable systems in Asian developing countries
9) The need for discussion toward construction of information strategy and business models in conjunction with the deployment of the smart grid.
10) The system must have added values from the viewpoint of users.
11) The need for urgent demonstrative implementation of the smart grid driven by public-private partnership.
12) The government is expected to develop the global deployment strategy, with an eye toward the market situations in developing countries.
13) The systems to be exported must be tailored to the situation of the target country (geographical, historical background, and needs)
14) The need for discussion as to the proper selection and coordination of the smart meter and household controller (home server).
15) The need for discussion toward proper ownership and installation of the smart meter.
16) The merit of introducing smart meters in the case charging scheme must be switched for mobile and house applications: usage of electricity is expected to extend to mobile (EV) applications.
17) The need for the review of security and the mechanism to share the cost, especially for controlling household appliances.
18) The need for an autonomous and effective network for the smart grid, when viewed as an entity that includes demand side users.
19) The need for the construction of the user participatory energy/social system.
20) The smart community presents a concept for municipal organization (Machizukuri) by providing “shared” space connecting “nature,” “place to live,” and “energy.”
21) Connecting household appliances to the smart grid will dramatically evolve an ordinary house into a theater of service provision.
22) The key points of discussion directly related to the introduction of smart meters: 1) the extent of functions that a smart meter should provide, 2) the issue of networks accessed (how the utility company network and public network should be compartmentalized), and 3) the level of openness that the public network should provide (scope for utilization of various communication providers).
23) Recipiency on the side of the consumers to demand-response services: a thorough understanding from consumers is needed as to the software (e.g. charging menu) from the viewpoint of best protecting consumer interests.
24) A thorough investigation is needed as to the cost burden and return on investment toward commercial realization of the smart community.
25) Careful distinction should be made as to the differences in services and cost burden in and outside of the smart community.
26) In conjunction with meter replacement for higher functionality, the time required for replacement and the effect it may have on metering performance should be taken into consideration.
27) Extended utilization of the smart meter should be investigated in the future (the possibility of application specific charges)
28) Both the public and self-initiative nature of the business should be considered, as well as regional characteristics and the facilities it possesses, before introducing smart meters.
29) The information handled in the home network should be classified from the viewpoint of security (open or closed system).
30) To gain overseas presence for the projects, thorough investigation of the regional legal system and local problems is needed, in addition to the enhancement of applications.
31) The importance of thorough explanation of the merits on the side of the users, and gaining understanding of the cost burden.
32) The importance of the discussion, from the viewpoint of the users, on how to draw incentives and encourage actions.
33) The utilization of existing infrastructure should be accounted for in the construction of the smart community.
34) To gain global presence, the smart community system to be exported must comply with the regional market pattern.
35) To help the private sector join an overseas project, government intervention is important to establish inter-government coordination.
36) The smart community project should be pushed forward as a combined and coordinated effort among environmental technology, financial technique, and public policy.
37) The concept of specific districts will play an important role for overseas deployment.
38) System thinking is always important: preoccupation with the performance enhancement of individual equipment will produce Japan-specific products.
39) For the commercial realization of the smart grid, an alliance between the public and private sectors, under the initiative of a government-led strategic framework, is most important, while maintaining ample scope for voluntary activities of the private businesses.
40) Patent strategy plays a key role in standardization strategy (i.e. open or closed system).
41) “Componentization” is also an important issue to be discussed, as well as system standardization.
42) Europe provides an eligible option when Japan contemplates international standardization.
43) Thorough investigation should be made as to which item should be completed by when, and it is important to define the time schedule based on this. Discussion should be made as to how to evaluate risks from a medium- and long-term prospect, and how to share the burden with the government.

and power systems will be realized. Expandability and mutual compatibility are the enablers to promote technology export to other countries, likely to provide the United States-bred renewable energy and ICT with a strong global competitive edge in the future.

On the other hand, Japan possesses a highly sophisticated electric power system, at least at present, and investment in technical development is focused mainly on renewable energy and storage. This situation in Japan is likely to promote development in renewable energy technology, and the element technologies will have a global competitive edge. However, it is also likely that they will be exported as "components" to be incorporated into a upper systems.

The value of a technology can be enhanced only when it is properly positioned and developed in the grand design. Especially, ICT can be considered as a vehicle to bring the grand design to reality. In terms of the smart grid, and from the viewpoint of ICT, being left behind in the train of research and development and the move toward standardization may isolate Japanese ICT from the mainstream of the smart grid market, just as was the case with the mobile phone.

5-2 Toward the world of "Internet of Things"

It would be worth mentioning that, in regard to the future smart grid, the following items were pointed out in the Smart Community Forum in Japan described in the previous section.[15]

- As the world of the information network, hitherto a closed network relating only to PCs and cellular phones, will extend itself to home networks that include household appliances, energy equipment, and automobiles, it will promote the emergence of the so-called "Internet of Things."
- Remote operation of demand-response, output control of photovoltaic generation, and charging time allocation of electric vehicles will become everyday matters, and utility companies' information control networks are connected to every household. This will promote a fusion of information networks and energy equipment (i.e. a smart house).
- These will promote the emergence of such systems as the new information network (2nd Internet), novel information networks connecting things to things and things to people, and systems that integrate energy equipment and information networks.

That is, the world of "Internet of Things," previously discussed with the words of RFID and IPV6, will further extend itself to include household appliances and automobiles accompanied by the smart grid, enabling the emergence of a new network where all objects (people, things, and energy) are connected

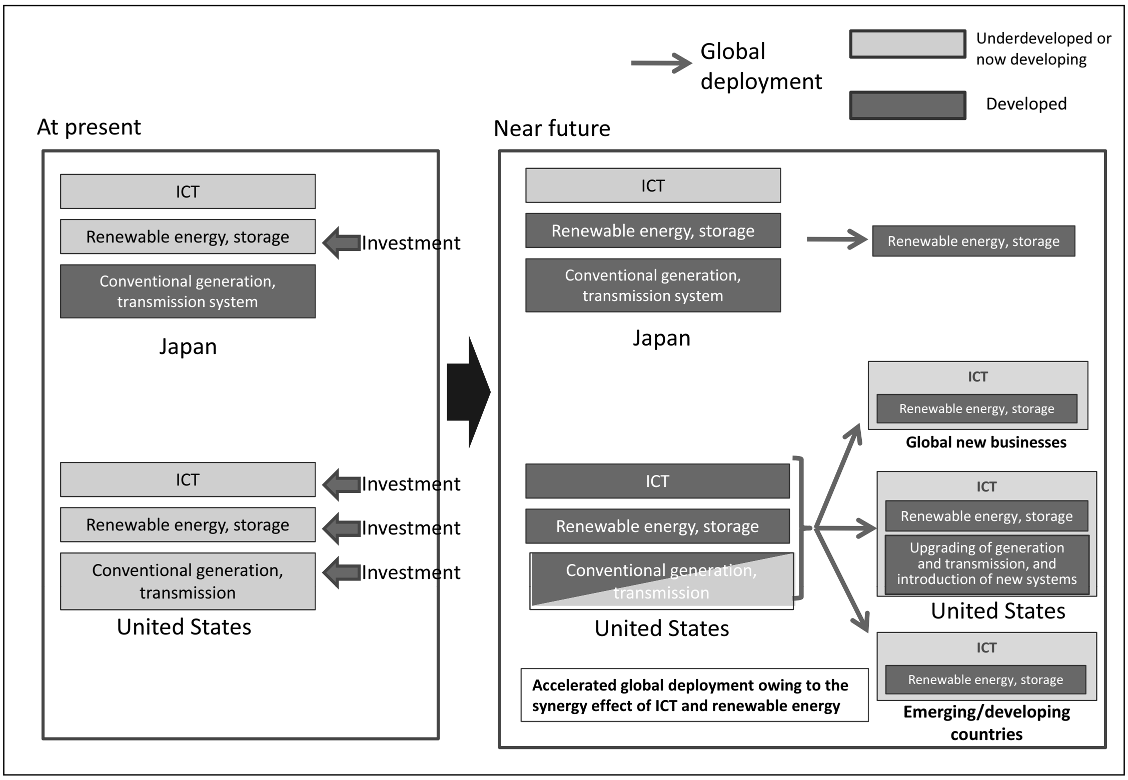

Figure 8 : Global Deployment Forecast of Technologies in Smart Grid

through information. This can be viewed as the popularization of informatization that takes place in the immediate vicinity of our lives, and has the potential of bringing major change in our society. The merit of this change resides in the fact that we will be able to realize a nearly totally optimized world, owing to the establishment of infrastructure that enables us to grasp all of the information regarding the instruments and objects in our home and society such as location/availability/resource consumption, and it will give us the ability to control them as well. On the other hand, there is a concern over the occurrence of security and privacy problems, hitherto being confined within the community of networked computers, in such daily objects as air-conditioners, refrigerators, and lighting fixtures.

IBM defines it latest business strategy as the realization of a "Smarter Planet." Smarter Planet is a concept aiming at realizing social and economic innovation by integrating physical phenomena, physical infrastructure, and digital infrastructure, by means of ICT, that surround every aspect of society - electric power, water, traffic, finance, logistics, and medical care. IBM predicts that Smarter Planet is capable of providing concrete solutions to such social and economic issues as saving energy, water shortage, traffic congestion, financial risk, lacking parts, and coordination of medical care. The concept of Smarter Planet can be viewed as a more generalized and expanded version of the Smart Grid. In the background of the strategy lies a concept that "information itself can set social and economic reality in motion." The concept underlying this strategy is a totally new thinking of "informatization": intimate attachment of digital infrastructure to the real world, and actions based on efficient information gathering and analysis will actually set the society and economy into motion.

Since the advent of computers, ICT has undergone an evolution supported by dramatic growth of such entities as semiconductors and computer networks, and it is now stepping into a new stage where ICT creates tangible values in society and economy. The objectives of the Smart Grid constitute one of the regions where the real-life challenges of ICT are tested.

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Profile

Kazuyoshi HIDAKA
Affiliated Fellow
Professor at Graduate School of Innovation Management, Tokyo Institute of Technology
At IBM Research (Tokyo), the author performed research on optimization technology, discrete algorithms, mathematical analysis technology, business solutions, mathematical organization theory and others. He was a project leader in some of the research. He also performed research at the IBM Watson Research Center (strategy section). He is a councilor in the Japan Society of Industrial and Applied Mathematics, a member of the Information Processing Society in Japan, and a member of the Operations Research Society of Japan. He joined the faculty of the Japan Advanced Institute of Science and Technology in August 2009. Doctor of Philosophy (science).

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3

Trends and Problems in Research of Permanent Magnets for Motors – Addressing Scarcity Problem of Rare Earth Elements –

Sumio KOZAWA
Affiliated Fellow

1 Introduction

One of the fundamental technologies necessary for the creation of a low-carbon society, such as next-generation vehicles and energy-saving home electric appliances, is the neodymium magnet for motors. The urgent issue facing neodymium magnets, for which demand has increased dramatically, is resource risk. In particular, the resource problem concerning dysprosium (Dy) is serious. Dysprosium is used in magnets for the motors of next-generation vehicles, such as hybrid cars, plug-in hybrid vehicles, and electric cars, in which the motors are exposed to a high-temperature environment.

Increasing the strength of magnets is expected to promote green innovation, as it contributes to the development of smaller and lighter motors with higher-torque, leading to the advancement of energy savings in a range of consumer products such as home electric appliances. As a result, it reduces the power consumption of motors, which accounts for approximately 52% of total domestic power consumption, further reduces the carbon emissions of next-generation vehicles, and enhances the performance of wind generators. Since the invention of KS magnetic steel by Mr. Kotaro Honda in 1917, Japan has proudly and consistently led the world in the development, production and application of magnets. Amid calls for Japan to respond to resource risk and promote green innovation, influential individuals in the industrial world are expecting measures to be taken to develop human resources for the research and development of magnets in order to promote innovation by mobilizing all magnet researchers in industry, government and academia.

Based on this recognition, the "Tohoku Motor Magnet Innovation Strategy Council" was established on June 17, 2010.[1] This report discusses trends and problems in the research of permanent magnets for motors.

2 History of Permanent Magnets

2-1 Yearly changes in Energy Product of Permanent Magnets

Humans discovered natural permanent magnets long before the time of Christ; people were using naturally magnetized iron ores in 600 B.C. in a region of Greece called Magnesia.[2-4] However, the first artificial permanent magnet was invented and named KS steel by Mr. Kotaro Honda in 1917. Mr. Honda, a thorough experimentalist, invented KS steel by experimenting with all possible combinations of minerals in the spirit of perseverance and effort.

Figure 1 (History of Permanent Magnet Development) shows that permanent magnets are 60 times as strong as they were about 90 years ago. Strong permanent magnets that can be used in industrial applications were developed in the 20th century, and Japanese researchers and technologies have always played major roles in the history of the development of permanent magnets. Following the invention of KS steel, Mr. Kato and Mr. Takei invented the OP magnet in the 1930s, which served as a base for the ferrite magnet. In 1932, Mr. Tokushichi Mishima invented MK steel, which served as the starting point for the development of the AlCoNI magnet. The coercive force of MK steel was 2 to 3 times as strong as KS steel. In 1933, Honda, Masumoto and others worked together to invent new KS steel, whose coercive force is about 1.5 times as strong as MK steel.

The performance of permanent magnets made a big leap forward thanks to the advent of rare-earth samarium-cobalt magnets in the second half of the 1960s. The samarium-cobalt magnet was invented by the U.S. Air Force Research Laboratory in 1968 and its performance has improved thanks to the contribution made by Japanese researchers, including Mr. Yoshio Tawara. In 1983, Mr. Masato Sagawa invented the neodymium magnet, which has remained the strongest permanent magnet in the world ever since.

Among the "Ten Great Japanese Inventors" selected by the Patent Office in commemoration of the 100th anniversary of the Japanese industrial property system, two magnet-related inventors made the list: Kotaro Honda (Patent No. 32234: KS steel) and Tokushichi Mishima (Patent No. 96371: MK magnetic steel).[5] More than 10 kinds of magnets were invented in the 20th century. Revolutionary discoveries and inventions drawing public attention were made only once every 20 to 30 years, suggesting that they were the results of long-term, challenging research.

2-2 Serendipity in Permanent Magnet R&D[8,9]

In the research of permanent magnets, it can be said that revolutionary new materials have been invented through serendipity (a propensity for making fortunate and unexpected discoveries by accident).

The story behind the development of the MK magnet by Mr. Mishima in 1932 is as follows. In order to examine why the magnetic transformation point of Fe-(25 to 26%)Ni alloy differs greatly depending on over-heating or cooling, Mr. Mishima began experiments to narrow the gap in transformation points by using aluminum as an added element. When shaving an aluminum-added specimen to a prescribed size, Mr. Mishima accidentally discovered that the shavings did not drop and instead clung to the specimen. This led to the development of the MK magnet (Fe-Al-Ni alloy). Although Dr. Mishima is not an expert in the field of permanent magnets, he did not overlook the accident thanks to his extensive knowledge and scientific acumen.

In 1970, Matsushita Electric Industrial Co. (now Panasonic Corporation) began industrial production of manganese-aluminum-carbon magnets produced through hot extruding and hot casting methods by adding carbon to manganese-aluminum magnets, which were developed by N.V. Philips in 1960. That magnet has excellent workability, so it is still used for

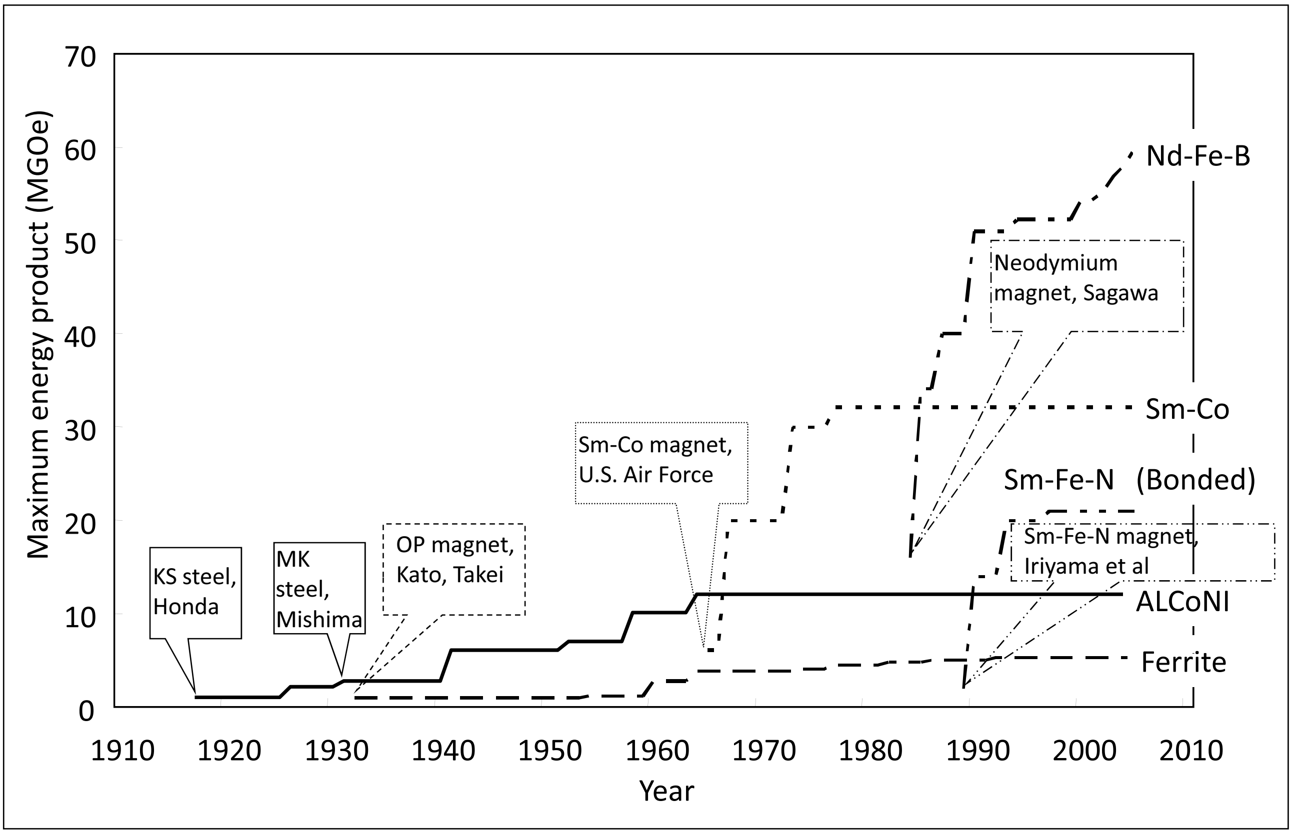

Figure 1 : Yearly changes in Energy Product of Permanent Magnets

Prepared by the STFC based on Reference[1,6,7] some purposes.[4] Since the manganese-aluminum magnet shows high crystal magnetic anisotropy, it was once touted as a potential candidate for a permanent magnet not containing cobalt. However, it has yet to be put to practical use. A group of researchers, led by Mr. Kubo of Matsushita Electric Industrial, once used an ordinary crucible to melt specimens during its research to put manganese-aluminum magnets to practical use. However, since impurities, such as Si, were mixed in with the melted specimens in the crucible, the group began to use a carbon crucible. As a result, the ingot mixed with carbon from the crucible and was powderized overnight. The powder was found to be a strong magnetic powder, leading to the development of the manganese-aluminum-carbon magnet.

The invention of the neodymium magnet by Mr. Sagawa in 1983 is said to have been prompted by a false hypothesis.[10] In 1978, Mr. Sagawa attended a study meeting titled “Rare-Metal Magnets: from Basics to Application” and was inspired to study magnets. Mr. Masaaki Hamano, in his speech at the meeting, explained that the reason R_2Fe_{17}, a compound of rare-metal R and iron (Fe), does not become a permanent magnet is that the ferromagnetic state of the intermetallic compound is unstable due to the too-small distance between the Fe atoms. Based on the fact that carbon in steel widens the distance between the Fe atoms in the steel, Mr. Sagawa hypothesized that the Fe-Fe atomic distance of R_2Fe_{17} can be widened, if it is alloyed with small-atomic-radius elements, such as C and B. Mr. Sagawa started experiments the next day, creating a variety of R-Fe-C and R-Fe-B alloys in an arc melting furnace, measuring their magnetism and examining their crystal structures. His research led to the invention of a neodymium magnet. Later, however, it became clear that the distance between the Fe atoms in $Nd_2Fe_{14}B$, the main phase of the neodymium magnet, is not very different from that in the B-free R_2Fe_{17} and that the improvement of the magnetic nature of Fe caused by B in $Nd_2Fe_{14}B$ was actually due to chemical interaction between Fe electrons and B electrons. Although Mr. Sagawa’s hypothesis at the beginning of his research was wrong, his research eventually resulted in developing the world’s strongest magnet thanks to his persistent efforts.

In 1990, a samarium-iron-nitrogen permanent magnet was invented by Mr. Iriyama and others of Asahi Kasei Corp. Mr. Iriyama had learned that a magnet can be invented by nitriding iron, after hearing a report by Mr. Minoru Takahashi that saturation magnetization improves if Fe is nitrided. Mr. Iriyama dissolved and nitrided Fe-30%mass%X alloy (with X being any available element in the periodic table), and eventually invented the Sm-Fe-N permanent magnet. Mr. Iriyama is also not an expert in the field of permanent magnets. If he was an expert in the field, he would not have thought of doing what he did. Since iron-nitrogen ($Fe_{16}N_2$) is soft phase, experts are inclined to think that even if saturation magnetization is increased by nitriding, the crystal magnetic anisotropy would not increase. This is another example of an outsider’s bold idea leading to the invention of a new chemical compound.

In this way, the invention of new permanent magnets has historically been brought about by bold interdisciplinary ideas, and passion and chance.

3 Current Status of Permanent Magnets for Motors

3-1 World’s Strongest Neodymium Magnet: Changing Motors around the World

Although electric magnets were previously used for rotating motors, neodymium magnetic plates have come to be used recently, especially for small motors, leading to a reduction in motor size and noise. Elevators were some of the first machines to use neodymium magnet motors. Then, neodymium magnets began to be used for washing-machine motors, increasing spin-dry power and reducing motor noise. Neodymium magnets are also now used in heavy machinery. Conventional hydraulic motors are noisy, as engines have to be kept rotating, but motors using neodymium magnets have made it easy to operate heavy machines in residential neighborhoods and at night.

In terms of numbers, neodymium magnets are most used in information equipment (Figure 2). A voice coil motor (VCM) is a linear motor that moves a voice coil placed in the magnetic field of a permanent magnet in proportion to electric current. VCMs are used as actuators for the head positioning of hard disks, for camera zooming, stopping down and shuttering, and for micromachinery. Neodymium magnets have also helped to make mobile phones thinner. The main challenge in making thinner mobile phones was to make speakers thin. By using an ultracompact neodymium magnet, it became possible to develop the world's thinnest speaker.

3-2 Neodymium Magnet: Trump Card for Energy Saving

In Japan, production of neodymium magnets mainly for use in information equipment has increased thanks to the spread of personal computers in the 1990s. In recent years, however, the proportion of neodymium magnets for use in motors has increased, so the production volume of neodymium magnets has increased sharply (Figure 3, Figure 4). The reason behind this is the fact that there are growing calls to reduce power consumption and increase the use of energy-saving equipment in order to cut CO_2 and other greenhouse gas emissions in line with the ratification of the Kyoto Protocol.

Thanks to neodymium magnets, the energy consumption of air conditioners has been drastically reduced. In air conditioners, electricity is mostly consumed by dive compressor motors.[12] Previously, AC induction motors were used for air conditioners, but inverter air conditioners were put on the market for the first time in 1981 and a highly-efficient brushless DC motor was developed in the 1990s. Following the enforcement of the revised energy conservation act in 1999 and the introduction of fuel efficiency standards under the act in 2003, all air conditioning manufactures started to improve their air conditioners and worked towards enhancing the performance of motors in order to drastically cut energy consumption. Most of the domestic air conditioning manufacturers adopted neodymium magnets in or after 2003 and have reduced the energy consumption of their products. Compared with conventional motors, new motors using neodymium magnets have reportedly improved their low-speed motor efficiency by approximately 30%.[13,14] However, non-inverter air conditioners are still more popular world-wide.

At present, induction motors not utilizing permanent magnets are extensively used in industry. If they are replaced by neodymium permanent magnet motors, it would significantly reduce energy consumption and help reduce CO_2 emissions.[14] At present, approximately 52% of Japan's total domestic power consumption is accounted for by motors. It is estimated that a 1% improvement in the efficiency of electric motors would save power equivalent to the output of a 500MW thermal power station.[14]

The products in which neodymium magnets have increasingly been used in recent years are automobile motors. If neodymium magnets did not exist, hybrid cars would not have been developed. The production of neodymium magnets has increased sharply in line with the expansion of hybrid-car production. As the production of next-generation vehicles, such as hybrid cars and electric cars, is expected to increase in the future, the production of neodymium magnets is also expected to continue to increase.

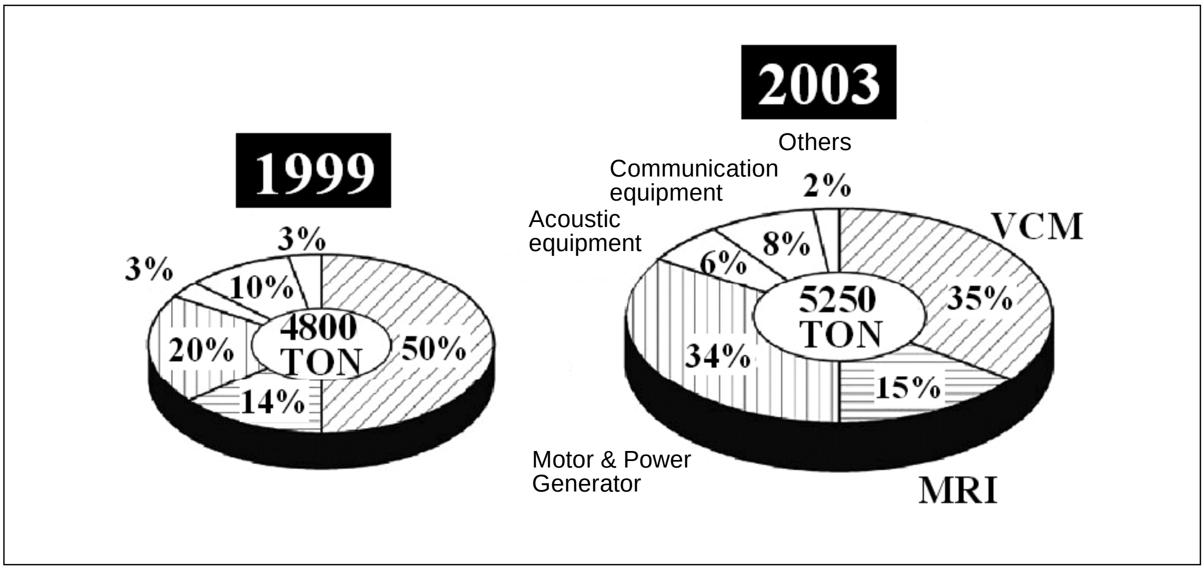

Figure 2 : Application of Neodymium Sintered Magnets in Japan

Source: Reference[2,11]

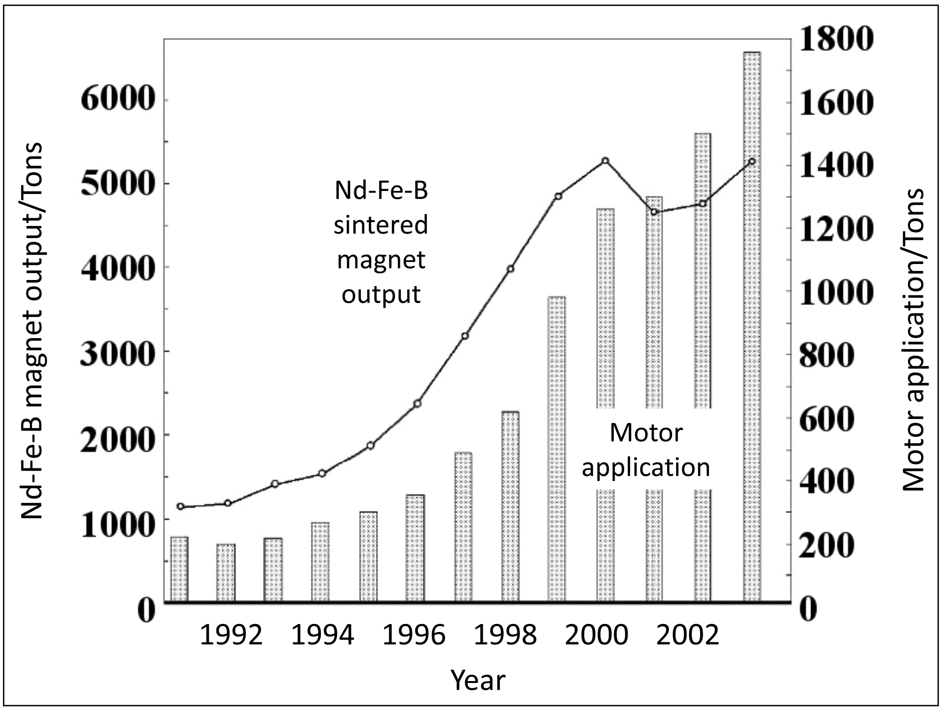

Figure 3 : Relationship between Neodymium Magnet Production and Motor Application in Japan

Source: Reference[2,11]

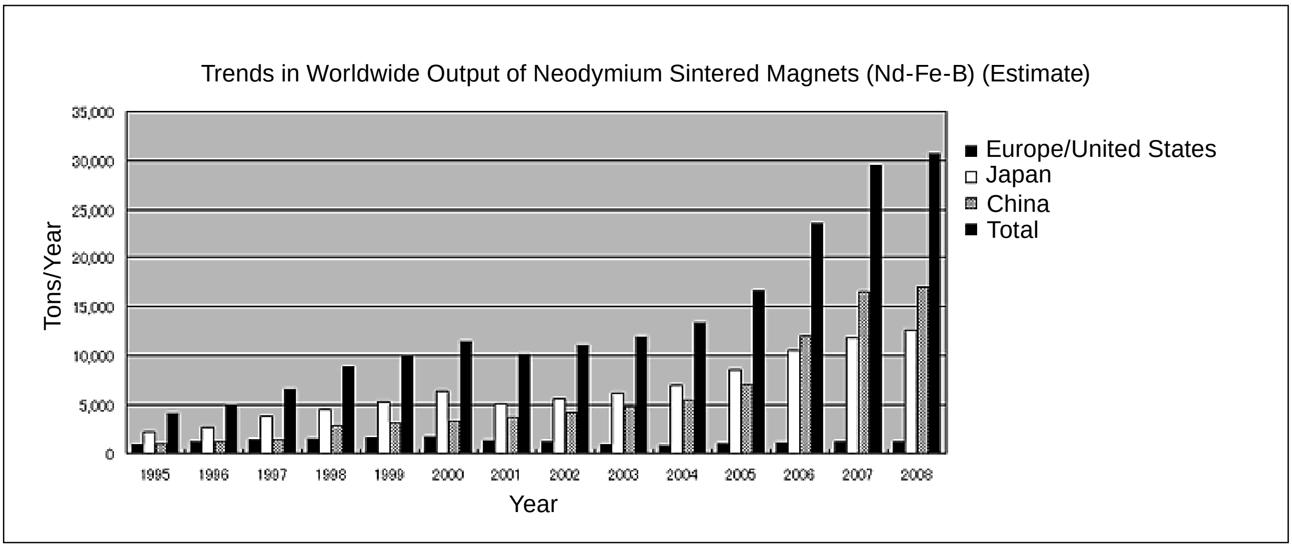

Figure 4 : Trends in Worldwide Production of Neodymium Sintered Magnets

Source: Reference[4]

4 Challenges of Permanent Magnet Motors and Research Projects

4-1 Challenges of Neodymium Magnets

Figure 5 shows the relationship between the application and composition of neodymium magnets. The temperature of a magnet, if used in a next-generation vehicle, reaches up to 200℃ while in use, but Neodymium magnets, in particular, are vulnerable to heat, while the coercive force of any magnetic material decreases as temperature increases. In neodymium magnets, the Curie temperature (the point at which magnetization falls to almost zero) of the $Nd_2Fe_{14}B$ compound is as low as 312 ℃ . Therefore, in order to increase the coercive force of neodymium magnets at high temperature, rare-earth dysprosium (Dy) is added. Figure 6 shows the product-by-product demand for dysprosium.

On the other hand, since the Dy that is added to $Nd_2Fe_{14}B$ substitutes for Nd and the magnetic moment of Dy causes it to be bound with Fe in an antiparallel manner, the magnetization of the magnet decreases due to the addition of Dy, and its maximum energy product (BH max) becomes small. Therefore, about 40% of the Nd in neodymium magnets currently used in next-generation vehicles is substituted by Dy in order to obtain a strong coercive force. As a result, the maximum energy product is about 40% smaller.

However, resource problems are more serious than the decrease in maximum energy product. Rare-earth metals have low dysprosium contents, with the ratio of its existence in rare-earth mineral ores to that of Nd being about 20%. Moreover, its origin is almost limited to China, raising concerns about a future supply shortage in view of an expected increase in demand for next-generation vehicles. For instance, the Next-Generation Vehicle Strategy Council, which is composed of the presidents of car manufacturers, has been strongly arguing that the research and development of Dy-free magnets through industry-academia-government collaboration is necessary.[17]

Furthermore, people in industrial and academic circles are calling for the development of more high-performance magnets. Since 25 to 30 magnets are used per vehicle, the development of more efficient magnets can lead to making vehicles lighter.[14,18] Enhancing magnet technology will also make motors for air conditioners more efficient.[19] Although the motor efficiency of Japanese home electric appliances is considerably high, the absolute number of motors is very high. As described in 3-2, motors account for 50 to 60% of the total domestic power consumption in Japan. Therefore, a 1% improvement in the efficiency of electric motors would reduce power consumption considerably. Moves to the use of electricity—from engines to motors and from hydraulic pumps to motors—have been progressing in various fields, as exemplified by next-generation vehicles. Therefore, the proportion of energy consumption accounted for by motors is expected to increase further in the future and this will increase the needs to enhance the performance of permanent magnets and motors.

4-2 Three National R&D Projects in Japan

With the aim of solving problems facing neodymium magnets, such as those described above, three national magnet R&D projects are now being implemented.

○ Rare Metal Substitute Materials Development Project, "Development of Technology to Reduce Dysprosium Used in Rare Earth Magnets"
- Implemented by the Ministry of Economy, Trade and Industry (METI) and the New Energy and Industrial Technology Development Organization (NEDO)
- Started in 2007
- Project to deal with the urgent issue of Dy resource problems
- Hereinafter referred to as "Technological Development for Dy-Saving Neodymium Magnets"

○ Element Science and Technology Project, "Project for High Performance Anisotropic Nanocomposite Permanent Magnets with Low Rare-Earth Content"
- Implemented by the Ministry of Education, Culture, Sports, Science and Technology (MEXT)
- Started in 2007
- Project is aimed at enhancing the performance of magnets as well as dealing with Dy resource problems
- Hereinafter referred to as "Nanocomposite Magnet Development"

○ Rare Metal Substitute Materials Development Project, "Development of New Permanent Magnets Substituting for Nd-Fe-B Magnets"
- Implemented by the Ministry of Economy, Trade and Industry (METI) and the New Energy and Industrial Technology Development Organization (NEDO)
- Started by using the supplementary budget (2nd) for 2009
- Project is aimed at enhancing the performance of magnets as well as dealing with Dy resource problems
- Hereinafter referred to as "Development of New Permanent Magnets"

In order to facilitate collaboration between the "Rare Metal Substitute Materials Development Project" by METI/NEDO and the "Element Science and Technology Project" by MEXT, a joint strategy council consisting of representatives from industry and academia has been established. The council sponsors a joint public symposium around February every year at the University of Tokyo to share research results and enhance collaboration.

4-2-1 Development of Technology to Reduce Dysprosium Used in Rare Earth Magnets (Technology Development of Dy-Saving Neodymium Magnets)

The project is designed to develop Dy-saving yet highly-coercive neodymium magnets for use in

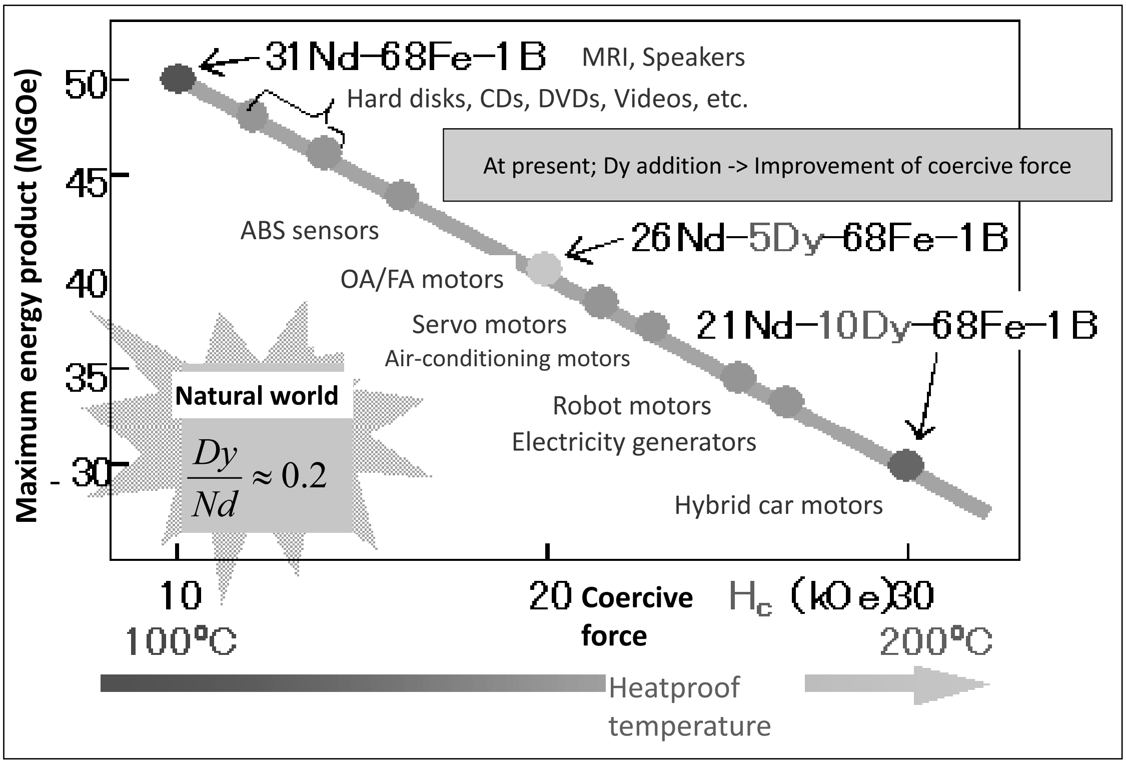

Figure 5 : Application and Composition of Neodymium Sintered Magnets

Prepared by the STFC based on Reference[15]

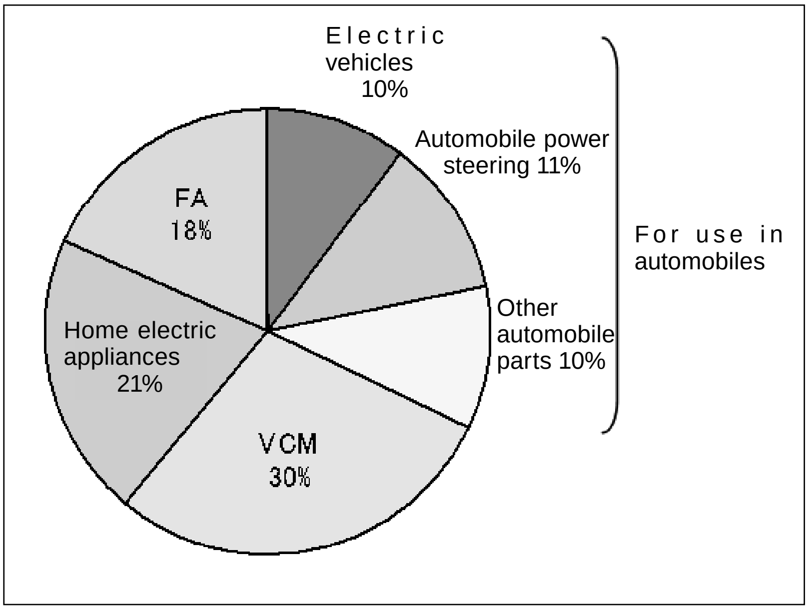

Figure 6 : Product-by-Product Demand for Dysprosium (Japan Market in 2004)

Source: Reference[16]

high temperature environments, aiming to reduce the amount of Dy consumed by such neodymium magnets by 30% in five years.

It is known that coercive force can be increased by reducing the probability of a reverse magnetic domain forming. It is thought that it is possible to do so by reducing the size of magnetic grains to single-domain grains (I in Figure 7) or by improving the coherency at interface of $Nd_2Fe_{14}B$, the main phase of the magnet (II in Figure 7).

The 7-I method is based on the knowledge that reducing the size of grains increases coercive force because it causes a relative reduction in the size of defects and an increase in the rate of crystal grains consisting of one magnetic domain (single-domain grain). Research and development is underway on production processes, including that of reducing crystal grain layer spaces of strip casting, which is an ingot production method, that of obtaining fine powder by operating jet mills at high speed, and that of developing a low-temperature sintering technique to curb grain growth at the sintering stage.[2] The process of miniaturizing crystal grains increases the surface area of grain, and thereby addresses the problems of controlling oxidation and increasing the homogeneous deposition of the Nd-rich phase on the surface at the same time. The 7-II method is designed to develop guidelines for process improvement by making model interfacial surfaces through thin-film technology and examining the best surface for increasing coercive force. So far, it has been found that, depending on the amount of oxygen melting in the Nd-rich phase (liquid phase) in deposits on grain boundaries, the interfacial situation changes and that an amorphous phase comes to exist on the surface. It has also been found that the coercivity of Nd-Fe-B magnets can be increased through high-field annealing.[20]

One of the features of this project is that production process technology development, like the 7-I and 7-II methods described above, is being promoted in a way to coordinate the acquisition of new guiding principles and the application development of automobile magnets. In order to find a new guiding principle, the project is trying to clarify the reasons that the current coercive force remains at about 10% of the theoretical value (90kOe) of the anisotropic magnetic field and that the coercivity of the grains decreases drastically when the size of crystal grains is reduced to a certain level, by analyzing the interface nanostructure of neodymium magnets and magnetization process. Furthermore, the project aims to obtain a guiding principle to enhance coercivity by using computing science and to pass the guiding principle on to production process technology development. Meanwhile, in the application development of automobile magnets, the project is examining the magnet durability assessment and the optimum shape of magnets that have been developed through the R&D of production processes in vertical collaboration with user companies and is passing the results of the examinations on to each R&D team.

A research evaluation committee made an interim evaluation of the results of this project study in October 2009. The committee said, “The project approaches the problem from two approaches based on the principle to increase magnetic coercivity, which enables reductions in dysprosium consumption: miniaturizing crystal grains and controlling the interfacial surface of grains. The project has cleared its intermediate target (achieved a 20% reduction in dysprosium consumption in FY2009). It will further strengthen Japan’s leadership in the field of ultra-strong magnets. The research papers announced are excellent in terms of their novelty.”[21]

4-2-2 Project for High Performance Anisotropic Nanocomposite Permanent Magnets with Low Rare-Earth Composition (Nanocomposite Magnet Development)

This Element Science and Technology project of the Ministry of Education, Culture, Sports, Science and Technology covers rather long-term research and

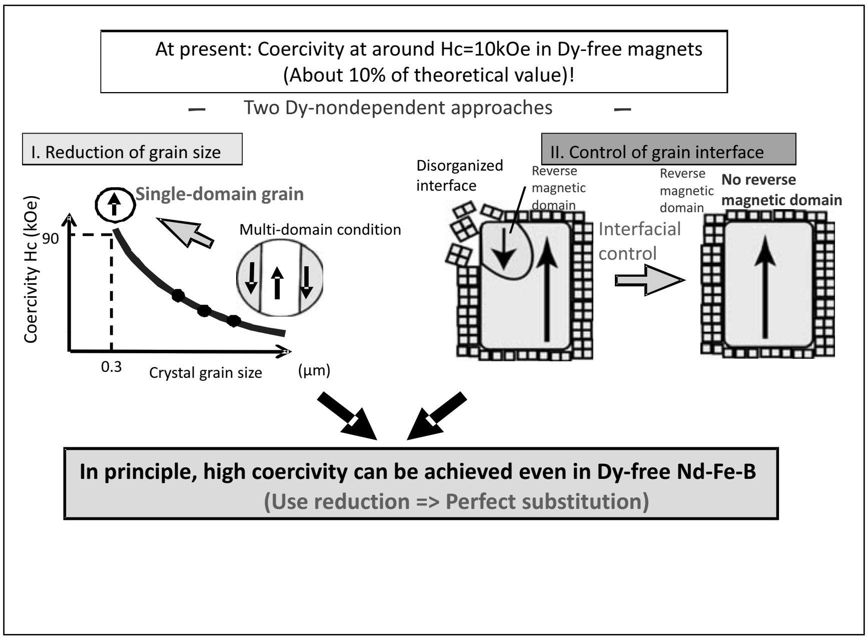

Figure 7 : Methods to Increase Coercivity of Neodymium Magnets

Source: Reference[15]

development projects.[22]

There are two approaches for enhancing the property of magnetic materials.[18] One of them is to find a completely new ferromagnetic compound that exceeds the $Nd_2Fe_{14}B$ compound. This approach is included in the project study objectives to be covered in the next section. The other approach is to form nanocomposites and it is being attempted in this element science and technology project.

The maximum energy product ((BH) max) of the current neodymium sintered magnet records a high of 60MGOe, approaching close to 64MGOe, which is the theoretical limit of the $Nd_2Fe_{14}B$ compound. Therefore, the magnet has only about a 10% margin left for enhancement. However, it may be possible to develop a neodymium magnet that exceeds the theoretical limit of $Nd_2Fe_{14}B$ by nanocompositing the hard magnetic materials for the $Nd_2Fe_{14}B$ compound and the soft magnetic materials with higher saturation magnetization, such as iron, and if the hard phase (hard magnetic phase) and the soft phase (soft magnetic phase) are magnetically connected.

The nanocomposite magnet is a concept discovered in the process of developing isotropic magnets by the liquid-quenching method. Around the same time that Mr. Sagawa invented a neodymium sintered magnet, Croat and others of General Motors Corporation developed a neodymium magnet as a bond magnet material, using the liquid quenching method.[18,23]

Magnetic materials used in industry are broadly divided into sintered magnets and bond magnets. Sintered magnets are anisotropic magnets in which the axes of easy magnetization of the crystal grains of the $Nd_2Fe_{14}B$ compound are oriented in the same direction. The maximum energy product of sintered magnets is high. On the other hand, bond magnets are isotropic magnets produced by liquid quenching nanocrystals of a magnetic compound and then solidifying them with resin. Therefore, their magnetic strength is about half that of sintered magnets. However, neodymium bond magnets are stronger than ferrite magnets and cheaper than neodymium sintered magnets and have shape flexibility.

Nanocomposite magnets consist of a nanoscopic hard phase and a nanoscopic soft phase but behave like single-phase magnets, as the two phases have exchange-coupling functions. Due to particle interaction, nanocomposite magnets produce higher remnant magnetization than the value theoretically expected from a completely isotropic microstructure. Since isotropic nanocomposite magnets have a lower Nd content than bond magnets, they are cheaper and more erosion resistant and are being commercialized as precursor powder for medium-property bond magnets.[18,24] Although isotropic nanocomposites have advantages in the sense that rare metals are scarce, they cannot be made stronger than sintered magnets due to their isotropic property. However, for more than 10 years some people have said that if nanocomposite magnets are made anisotropic by directionally controlling their axis of easy magnetization, it should be possible to obtain properties surpassing those of sintered magnets.

However, no researcher has yet to succeed in aligning crystal orientation on the nano scale. Moreover, there is another unsolved problem that nanocomposite magnets are unable to generate strong coercive force: the conventional research of neodymium magnets has failed to overcome the shortcoming that the coercive force of a neodymium magnet decreases sharply when the volume ratio of its soft phase is increased.[25] This is due to the deficient perspective of controlling the internal textures of materials for generating coercive force. Amid calls for reductions of dysprosium, increasing coercive force has become more urgent than increasing magnetization.

Therefore, in the development of high-performance anisotropic nanocomposite magnets with low rare-earth composition under the MEXT's Element Science and Technology Project, efforts are being made to develop highly-coercive basic magnetic powder and highly-coercive metallic nanoparticles, and to clarify their tissue growth and coercive force generation mechanism, while aiming at creating anisotropic nanocomposites of Fe and $Nd_2Fe_{14}B$ compounds and achieving a coercive force stronger than neodymium magnets without using Dy and concurrently with reducing the use of Nd.[26] The project study is designed to achieve technology to maintain the coercive force without using Dy but by making the size of crystals one-digit smaller than neodymium sintered magnets. Since the conventional method of miniaturizing easily-oxidizable $Nd_2Fe_{14}B$ compounds has its limits, the HDDR process is being experimented with in making powder particles with an anisotropic texture and high coercive force. The HDDR process is a process to break down single-crystal particles to nanocrystals in high-temperature hydrogen and then make polycrystals with an anisotropic texture by removing the hydrogen. The HDDR process is an interesting process in that recombined crystals can be brought back roughly to their original orientation by subtly controlling reaction conditions. Their grain size is about one-tenth that of neodymium sintered magnets.

The project study is also designed to find a theory to increase coercive force without depending on the crystal magnetic anisotropy of rare earths, such as Nd. Even when crystal grains are miniaturized to reduce the use of Dy, the magnetic anisotropy of Nd and other rare earths still decreases sharply as their temperature is raised. However, since the magnetic anisotropy of iron is less dependent on temperature, if the crystal magnetic anisotropy of iron in rare-earth iron compounds can be utilized, the effect of temperature on the coercivity of magnets can be reduced. As for the hard phase, powder particles with anisotropic internal tissues are made. Although this technology was invented in the 1980s, few researchers have actually utilized it and there are only a few hypotheses concerning tissue growth. Meanwhile, regarding the soft phase, although there is technology to reduce the size of grains to 5 to 10nm, techniques such as those for judging the advisability of applying the technology to compounding processes and compounding the technology into the hard phase, have yet to be established. Therefore, there is a host of challenging issues, including the fact that the surface becomes easily oxidized in the process of producing nanoparticles.

Since there are many issues that have yet to be clarified or resolved in this research project, including the tissue growth mechanism, coercivity generating principle, and technology for producing anisotropic magnetic particles, the first thing to do is attempt to understand mechanisms by studying new magnetic domain observation means and conducting tissue analyses in microscopic areas. Since this research project involves challenging basic research, it is not designed to put technology to practical use by the end of the project period. Rather, its purpose is to ascertain at the end of the project period whether it is possible to industrially produce practical magnetic materials based on nanocomposite magnets in the future.

4-2-3 Development of New Permanent Magnets Substituting for Nd-Fe-B Magnets (Development of New Permanent Magnets)

In March 2010, "Rare Metal Substitute Materials Development Project: (I) Development of New Permanent Magnets Substituting for Nd-Fe-B Magnets and (II) Development of Yttrium Compound Materials for Ultra-Light, High-Performance Motors" was launched as a METI/NEDO project.[27] This project, which is designed to contribute to ensuring the stable supply of rare metals, such as Dy, was inaugurated as part of an emergency economic package (2nd supplementary budget for FY2009). It called for setting a detailed goal that can be achieved during the implementation period after consultation among the New Energy and Industrial Technology Development Organization (NEDO), theme leaders and adopters.

The theme adopted for Project (I) is in essence developing new permanent-magnet materials by using iron-nitrogen compounds. By using readily-available iron and nitrogen as the main raw materials, studies are being made to explore high saturation magnetic flux and high magnetic anisotropic magnets with properties potentially exceeding those of current neodymium magnets. Specifically, it is planned to obtain technical guidelines for synthesizing a desired phase of iron nitride and to build technology to produce bulky R-Fe-N through the analysis of nano-level microstructures and their formation process, and through evaluation of their magnetic characteristics, focusing on iron nitride materials and rare-earth R-Fe-N. The ultimate goal is to contribute to the realization of a low-carbon society by developing new permanent magnets for use in electric and hybrid car motors.

Project (II) is not for the research and development of permanent magnets. Rather, it is designed to develop yttrium (Y) compound materials in order to realize next-generation motors that can replace current motor parts.

4-3 Overseas Production and R&D Status[28]

As Figure 4 shows, neodymium sintered magnets are currently produced mainly in Japan and China. In the 1990s, Japan was the largest producer, while China's and Western countries' production levels were about the same. Then, production in Japan and China increased, but in 2006 China surpassed Japan as the world's largest producer of the magnets. Although Japanese-made neodymium sintered magnets are reputed to be the best in the world in terms of magnetic property, China has become the world's largest producer of the magnets, backed by low cost and abundant resources. Asian countries, including China, South Korea and Taiwan, have intensified their magnet research activities.

Although the number of Japanese-made neodymium sintered magnets used in hard disks and other information equipment has increased as described in Chapter 3, information equipment's share of total neodymium sintered magnet production has decreased due to the effect of smaller and lighter information equipment. On the other hand, the shares of neodymium sintered magnets used in air conditioners and automobiles have increased. In China, about 29% of the neodymium sintered magnets produced in the country was accounted for by use in such products as electric bicycles, VCMs and MRIs, about 44% by such products as speakers and magnetic separators, and about 20% by low-grade applied products, according to 2004 statistics. Chinese-made neodymium sintered magnets have yet to be used in such fields as next-generation car engines in the country. For products requiring high-performance magnets, Japanese-made magnets have been mainly used.

In the 1960s, the U.S. magnet industry was the strongest in the world, but now it has almost disappeared. The United States has not produced neodymium sintered magnets since 2005, after producing about 100 tons in 2004. Most recently, however, concerns have been raised from some quarters, including the military, about the fact that the United States relies completely on China and Japan for its supply of electromagnetic conversion-related devices. This has prompted some researchers to try to revive the country's magnet research. For instance, a group of 44 researchers from industry, academia and government, led by Prof. George C. Hadjipanaysis of the University of Delaware, hosted "The Future of High Performance Permanent Magnets in the U.S.A.," a workshop aimed at revitalizing the research of advanced magnetic materials in the country.

In Europe, although well-known magnet makers are still in business, their production of neodymium sintered magnets in 2007 was about 800 tons, two orders of magnitude smaller than Japan's and China's. Magnets imported from China have increased in European markets. However, since Europeans still think that researching permanent magnets is one of the important components of a sustainable society, European motor manufacturers have begun to contact Japanese magnet researchers actively.

5 Future Approach to Basic and Generic Research in Permanent Magnets

With the trends and problems in the research of permanent magnet motors discussed above in mind, I would like to make my recommendations on how to promote basic and generic research of permanent magnets in the future.

Researching permanent magnets is a challenging project requiring a long period of time. At the same time, however, most of the groundbreaking inventions and discoveries have been put to practical use, producing a major impact on green innovation. Therefore, the input of public funds into basic and generic research aimed at contributing to green innovation, like the national R&D projects described earlier, should be increased and continued.

Table 1 shows the number of participants in recent academic conferences and the number of presentations made at the conferences. Although these numbers alone do not show it clearly, the activities of magnet-related academic societies in Japan have begun to show signs of being reactivated since 2007, when agenda-set national projects concerning the R&D of permanent magnets were inaugurated. The recognition that this area of research has come to be reactivated was shared at a meeting of the Tohoku Motor Magnet Innovation Strategy Council held on June 7, 2010, with a total of 219 industry, academia and government representatives in charge of magnets and the regional economy attending.

It would be meaningful to shed light on important objective basic research for solving green innovation issues, including the R&D of permanent magnets, and to promote such research in a top-down manner. Assuming that the investment efficiency of research and development is constant, if investment in a research and development project is increased and the number of researchers participating in the project also increases, the time required for making a groundbreaking invention or discovery is expected to be shortened.

Needless to say, it is necessary to strive to increase R&D investment efficiency, not to mention the investment amount. Since neodymium magnets are extremely high-quality finished magnets, it is hard to achieve a breakthrough in material composition exploration without a guiding principle. The research of magnets so far seems to have been pursued by industry, guided by experience and intuition. However, such an approach has come to its limits and universities are being asked to come up with a new guiding principle. Fortunately, great progress has been made with measuring technology. For instance, by using such techniques as multiscale analysis, NMR measurement and neutron line diffraction, it has become possible to measure what could not be measured before. Also, the progress made in computer science based on first-principle calculations is expected to advance new theoretical analyses, contributing to material development. For example, in the "Technology Development of Dy-Saving Neodymium Magnets," which was discussed earlier, progress has been made in clarifying the interrelation between grain-boundary composition/structure and coercivity/internal construction, and in shedding light on the relationship between a microparticle's anisotropy and its surface by measuring the magnetic property of the microparticle group. In this way, by combining structure and mechanism analysis utilizing advanced measuring techniques with theoretical analysis utilizing computing science, a new guiding principle for material development should be established in order to find new chemical compounds and organize magnetic alloys (Figure 8). This type of teamwork research has already been tested in some national R&D projects, for example, "Technology Development of Dy-Saving Neodymium Magnets." It is desirable to continue and expand such efforts.

At the same time, however, the invention of new permanent magnets has been historically brought about by bold interdisciplinary ideas, passion and chance, as described in 2-2. Researching magnets requires a variety of expert knowledge: physics and metallurgy for the research of magnetic materials, electromagnetic engineering for the development of magnets, and machine engineering and electronics for their application. Magnets are important material elements to connect electric energy and machine motion in order to convert energy into movement and vice versa. However, as described in 4-2, there are many phenomena that have yet to be theoretically explained. Hence, the participation of researchers in various specialized fields is required. For instance, it is necessary to promote the participation of researchers not only in the department of engineering but also in the department of science. This raises the necessity of promoting proposal-based research, based on the free thinking of individual researchers. As a bottom-up approach to promote the participation of researchers in different fields, it would be beneficial to establish a kind of competitive research funding that encourages agenda-set development competition.[29]

It would be useful to develop the style of Scientific

Table 1 : Trends in the Number of Participants in Magnet-Related Academic Conferences and the Number of Presentations

Magnetics Society of Japan, Hard Magnetic Materials Study Group

Calendar Year	1984	1987	1988	1991	1994	1996	1998	2001	2003	2005			2008
										First	Second	Third	
Number of participants	192	178	144	118	111	63	96	98	64	75	38	68	46

Japan Institute of Metals

Year	2006		2007		2008		2009		2010
	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring
Number of presentations on hard magnetic materials	12	4	9	5	14	19	33	25	16

(Note); The 9 cases in the spring of 2007 include one symposium and the 33 cases in the spring of 209 include 27 symposiums.

Institute of Electrical Engineers of Japan, Division A meeting (Magnetic materials, etc.)

Year	2007	2008	2009
Number of participants	192	178	144

Prepared by the STFC based on academic societies' data

Research on Priority Areas consisting of planned and proposal-based research in the Grants-in-Aid for Scientific Research under the collaboration of industry, academia and government. In other words, we need a system designed to promote both planned research at centers of excellence under industry-academia-government collaboration and proposal-based research following agenda set by project leaders of planned research under said collaboration. Figure 9 illustrates the problems involved in the development of permanent magnets and R&D approaches to solve them.

Acknowledgment

This report is based on speeches by the members of the Tohoku Motor Magnet Innovation Strategy Council and their discussions at Strategy Council meetings. Among the speakers are Yoshikazu Goto, councilor at the Ministry of Economy, Trade and Industry, Katsuhiko Ito, deputy governor of Miyagi

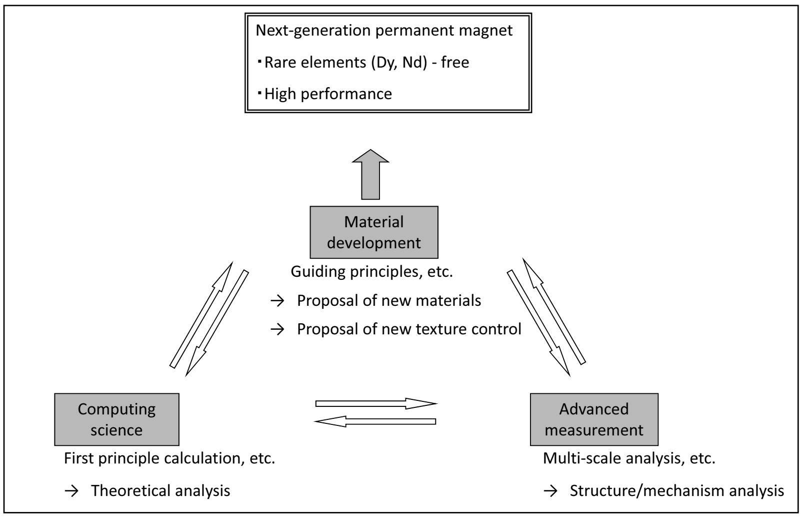

Figure 8 : Approach to Basic and Generic Research of Permanent Magnets for Motors (Teamwork-type planned research)

Prepared by the STFC

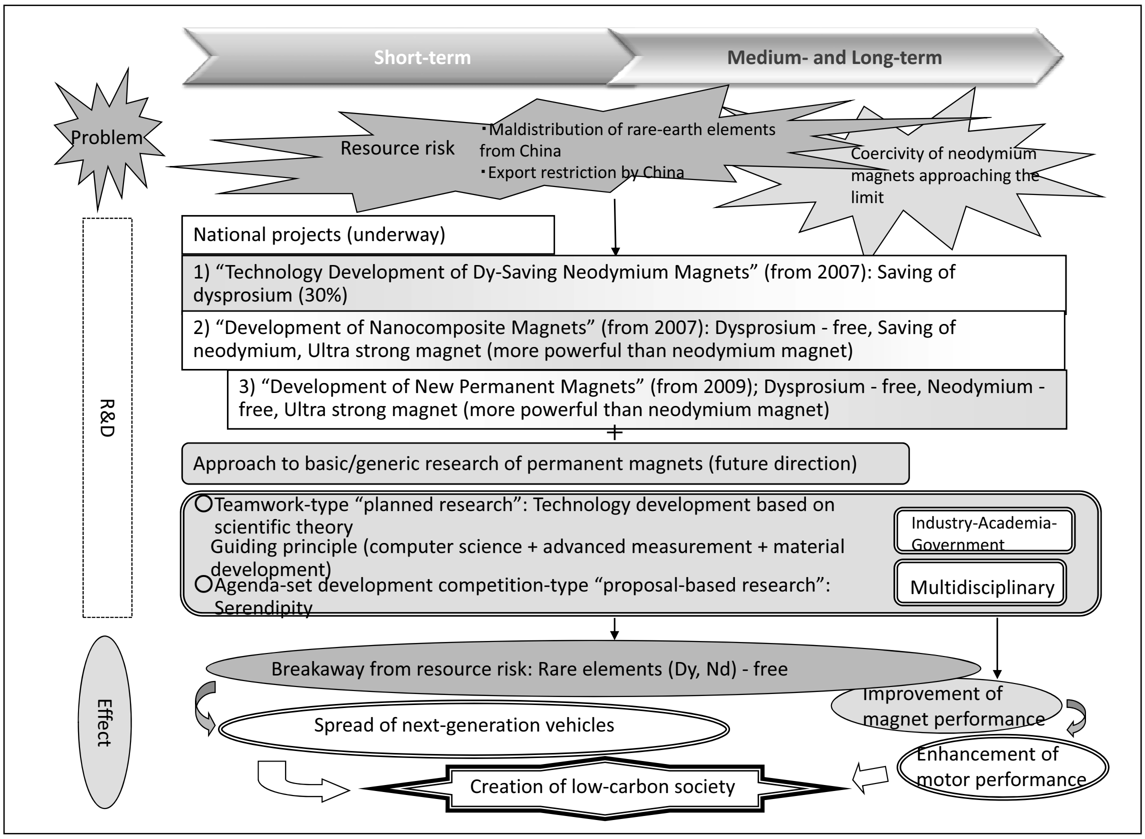

Figure 9 : Problems with Permanent Magnets and Approach to Basic/Generic Research

Prepared by the STFC

Prefecture, Yoshio Endo, executive director of the Tohoku Economic Federation, Masataka Muramatsu, Toyota Motor Corp. director, Hideki Harada, chief executive officer of the Japan Association of Bonded Magnetic Materials, Yasuo Iida, program manager at the New Energy and Industrial Technology Development Organization, Takeshi Nishiuchi, senior researcher at Hitachi Metals Ltd., Masato Sagawa, president of Intermetallics Co., Kazuhiro Hono, fellow at the National Institute for Materials Science, Hiroshi Kazui, chief of the Tohoku Bureau of Economy, Trade and Industry, Ko Kumagai, president of Tohoku Innovation Capital Corp., Satoshi Kawakami, operating officer at Tokyo Electron Ltd., Akihisa Inoue, chancellor of Tohoku University, Satoshi Sugimoto, professor at Tohoku University, Ken Takahashi, professor at Tohoku University, Masuo Okada, professor at Tohoku University, and Akira Miyamoto, director at the Industry Creation Hatchery Center. I would like to take this opportunity to extend my deepest gratitude to each of them.

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Profile

Sumio KOZAWA
Affiliated Fellow, NISTEP
Professor, New Industry Creation Hatchery Center, Tohoku University
http://www.niche.tohoku.ac.jp/

Dr. Kozawa (Engineering) has been in his current position since July 2008, after working for the Japan Delegation to the European Union, the Energy Charter Secretariat, the Japan National Oil Corporation, the Ministry of Economy, Trade and Industry, and NEDO. He is currently engaged in the development and planning of project studies, based on the potential of universities, to solve industrial and social problems through collaboration with outside organizations.

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4

Development of an Earthquake Early Warning System and Its Benefits

Shozo MATSUMURA
Affiliated Fellow

1 Introduction

The ground motion of an earthquake resembles thunder in a sense. A person who witnesses bright lightning in the night sky prepares himself or herself for the thunder that is anticipated to follow. This time lag results from the velocity difference between light and sound. In the case of an earthquake, the velocity difference between the primary wave (P-wave) and the secondary wave (S-wave; generally, the S-wave has a larger amplitude than the P-wave, and, in the case of a nearby earthquake, the peak ground motion (principal motion) often arrives immediately after the S-wave) generates a time allowance which enables a person to start preparing for the principal motion as soon as he or she detects the preceding P-wave. Moreover, by installing seismographs near the source and analyzing the P-wave data detected by the seismographs, it will be possible to give warnings to distant locations before the P-wave arrives at those locations.

If an advance warning of ground motion can be given effectively, the number of casualties from collapse of buildings and other earthquake damages could possibly be reduced. Even when the ground motion is not so strong, such warning could contribute to reducing economic losses through automatic shutdown of machines. Furthermore, system development related to such warnings may create new business opportunities. The idea of a system for advance warning of ground motion, which was considered to be promising in various aspects as explained above, already existed from long ago. However, in order to actually build such a system, an appropriate observation network, analysis system, and communication system would essentially be required. A total renewal of Japan's seismic observational and research infrastructure triggered by the 1995 Great Hanshin-Awaji Earthquake Disaster laid the basis for putting such idea into practice.

In October 2007, the Japan Meteorological Agency (JMA) embarked on practical implementation of such idea, that is, actual operation of the Earthquake Early Warning (EEW) system[1] based on the results of its research and development efforts. During the two and half years from then until March 2010, a total of 14 EEWs were issued via television, etc. and EEWs became widely recognized and have taken root among people (these EEWs are categorized as Alerts which are explained later in this article). During this period, although there were some malfunctions caused by erroneous transmissions and seismic intensity prediction errors, the performance of the EEW system more or less fell within the anticipated scope, and EEWs were favorably reported by mass media as a case example in which results of seismic studies have been directly put to beneficial use in peoples' lives. However, since the time allowance generated by an EEW is just about sufficient from a workable standpoint, how EEWs' realistic effects can be optimized remains as a future challenge.

Practical implementation of EEWs also drew attention in terms of its technology development aspect, and the details of the technology development were introduced in *Science & Technology Trends* on three occasions.[2–4] As for the mechanism of the EEW system[5] and its usage guidelines,[6] see the detailed explanations available on the JMA website.[7] This article gives an outline of the mechanism of the EEW system, its development history, and actual state of its operation, as well as focuses on the *regressiveness* whereby the time allowance becomes shorter as the seismic intensity becomes larger, as a practical problem, and develops an argument with an eye on the limits of EEWs, while also providing the author's views.

2 Contents and Positioning of EEWs

2-1 Mechanism of the EEW System

The principle of the EEW is, as Figure 1 shows, to presume the source information (location and magnitude) using the P-wave that has arrived at the observation point nearest to the source in the nationwide seismic observation network, calculate the ground motion that is expected to occur at various locations based on this presumption, and transmit the result before the arrival of the principal motion. Because the principal motion generally arrives immediately after the S-wave, the system aims to transmit an EEW before the arrival of the S-wave. The JMA has developed a method to presume the source location and the magnitude based on information obtained at only the single nearest observation point, and sends the result derived from information at such single observation point as a first report. However, since the first report contains substantial uncertainties, the JMA sends a second report and a third report by also using the seismic waves that have arrived at the second and subsequent nearest observation points.

Although the principle is thus simple and clear, the actual situation is quite complicated, as indicated in the following specific example. There are a total of about 1,000 observation points nationwide, combining about 200 multifunctional seismographs of the JMA and about 800 high-sensitivity seismographs (Hi-net) of the National Research Institute for Earth Science and Disaster Prevention (NIED). The average distance between these points is about 20 km. Therefore, in the case of an inland earthquake, the average horizontal distance to the nearest observation point will be about 10 km, which will be used as the representative value. When the depth of the source is assumed to be 10 km, the source distance to the nearest observation point will be about 14km. Figure 2 shows a time chart where an EEW is received at a location farther away from the source than the observation point, with a source distance of 30 km. While the seismic wave velocity differs by depth, the P-wave velocity at the depth of 10 km was assumed to be 6km/sec. and the S-wave velocity at the same depth to be 3.5 km/sec. Further, the delay expected when passing through a shallow layer[8] was also taken into consideration in the estimation. The P-wave arrives at the nearest observation point 3.0 seconds after the earthquake occurrence. Under the present conditions, it takes about 5.5 seconds on average to transmit the first report, so the first report reaches the target location 8.5 seconds after the earthquake occurrence. Since the S-wave arrives at the target location 10.7 seconds after the earthquake occurrence, the EEW will be just about in time for the principal motion in this case. However, given that a transmission delay will occur in real circumstances, we need to consider that in the case shown in Figure 2, that is, at a location within a 30 km radius from the source, the EEW will not practically reach the recipients in time. The *earthquake disaster belt*,[NOTE] which appeared at the time of the Great Hanshin-Awaji Earthquake Disaster (M7.3), roughly coincides with this 30 km-radius zone. Therefore, even if the EEW system did exist at the time, the EEW unfortunately would not have reached the recipients in time. Because of this, the JMA indicates the following notice: "In areas that are close to the focus of the earthquake, the warning may not be transmitted before strong shakes hit." Of course, if the distance becomes longer, the time allowance will also become longer. In this estimation as well, the time allowance increases by about 3 seconds for every 10 km distance away from the source. In the case shown in Figure 2, the P-wave arrives at the target location 5.7 seconds after the earthquake occurrence, so the preceding P-wave shaking will have already started at the target location before the arrival of the EEW. Accordingly, if the later-mentioned ground-motion-detecting control system operates with the arrival of the P-wave, about 5 seconds of time allowance can be secured before the arrival of the S-wave.

2-2 Positioning of EEWs

At present, four types of earthquake-related information are issued by Japanese public organizations (Table 1): (i) Strong Ground Motion Prediction; (ii) Earthquake Prediction (currently only

[NOTE]
The *earthquake disaster belt* refers to a belt of land along Kobe's urban area that suffered concentrated damage in the Hanshin-Awaji Earthquake Disaster. Ground motion is considered to have been amplified due to its unique subsurface structure composed of a fault and a sedimentary basin.

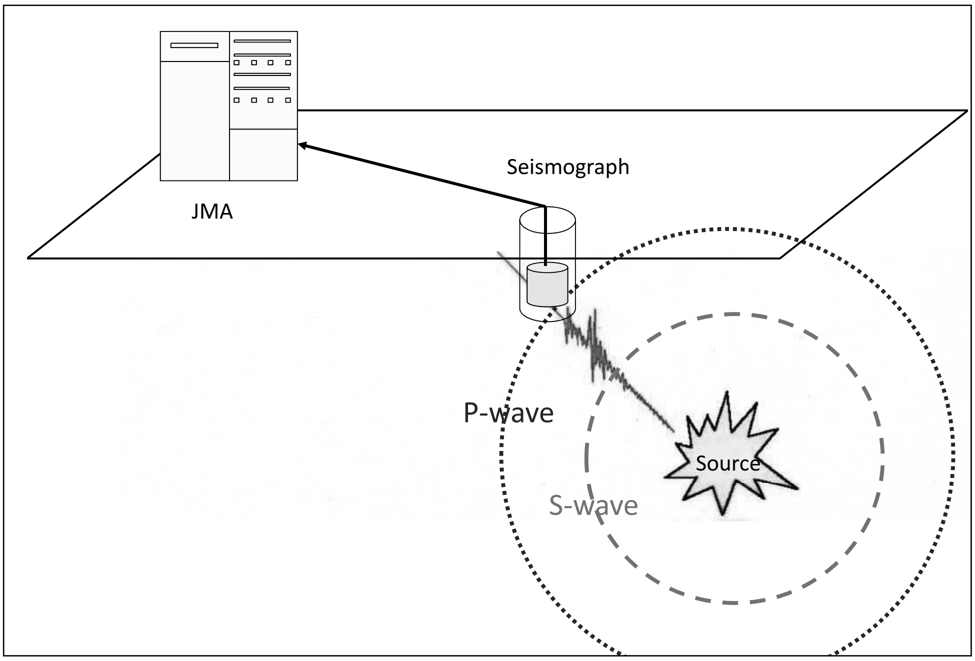

Figure 1 : Principle of the Earthquake Early Warning

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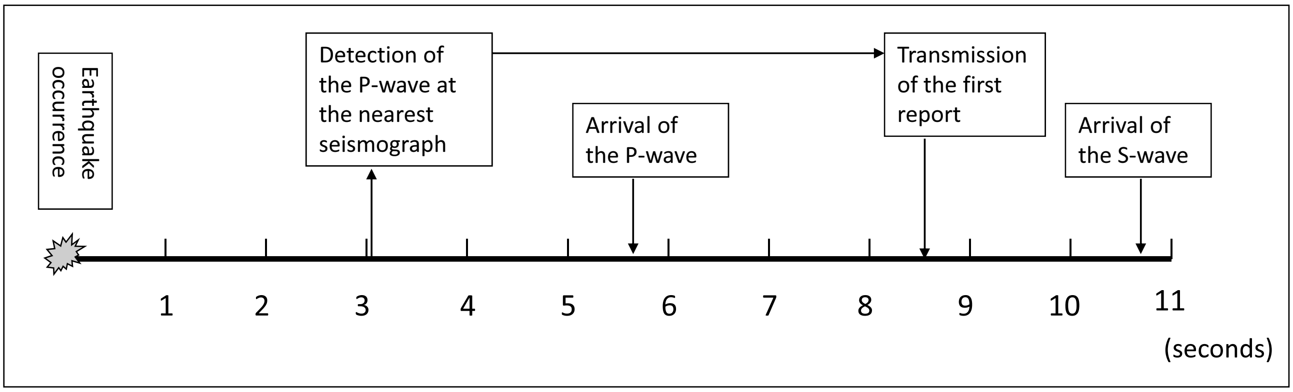

Figure 2 : Time Chart of the Seismic Wave and Transmission of an Earthquake Early Warning (Source Distance =30 km)

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targeting Tokai Earthquake); (iii) Earthquake Early Warning; and (iv) Earthquake Information. These are listed in the order of time sequence in relation to the earthquake occurrence. The information listed in (i) and (ii) is issued before the earthquake occurrence, and the information listed in (iii) and (iv) are issued after the earthquake occurrence. The EEW indicated in (iii) can be positioned as a safeguard based on the assumption that general earthquake prediction is not possible at present, while at the same time, it can be regarded as information issued prior to (iv) Earthquake Information aimed at identifying the status of disaster caused by an earthquake occurrence.

2-3 Categories of EEWs

As Table 1 shows, the EEWs are categorized into an Advance Notice of Ground Motion (hereinafter referred to as an "Advance Notice") and a Ground Motion Alert (hereinafter referred to as an "Alert"). While these categories are strictly defined, a simple criterion for their issuance is whether or not ground motion with a seismic intensity of 5 lower or greater is predicted. If the predicted ground motion is less than seismic intensity 5 lower, only an Advance Notice is issued, and if it is 5 lower or greater, an Advance Notice as well as an Alert are issued. An Advance Notice is issued via the Japan Meteorological Business Support Center to expert users who have dedicated terminals. An Alert is issued via television, radio, mobile phones, and anti-disaster radio communication systems to residents of areas where ground motion with a seismic intensity of 4 or greater is predicted. The former entered into operation in August 2006 and the latter in October 2007.

Table 1 : Principle of the Earthquake Early Warning

No.	Item	Time Span	Category	Contents	Issuer	Media
1	Strong Ground Motion Prediction	30 to 50 years earlier	30 year probability	Probability of occurrence of an earthquake of seismic intensity 5 lower, 5 upper, 6 lower, or 6 upper during the relevant period	Headquarters for Earthquake Research Promotion of the Ministry of Education, Culture, Sports, Science and Technology	Booklets, newspapers, and the NIED website
			50 year probability			
2	Earthquake Prediction	A few hours to a few days earlier	Tokai Earthquake Report	Occurrence of a phenomenon that cannot be immediately determined to be a precursor/occurrence of a notable earthquake within the assumed source area though not related to a Tokai Earthquake	JMA	Television, radio, newspapers, and the JMA website
			Tokai Earthquake Advisory	Occurrence of a phenomenon that is likely to be a precursor		
			Tokai Earthquake Warning	Announcement that a Tokai Earthquake is expected to occur		
			Warning Statement	Statement warning of occurrence of a Tokai Earthquake	Prime Minister	
3	Earthquake Early Warning	A few seconds to a few tens of seconds earlier	Advance Notice of Ground Motion	Transmitted when ground motion with a maximum seismic intensity of 3 or greater or a magnitude of 3.5 or greater is predicted	JMA (licensed business operators)	Dedicated terminals, etc.
			Ground Motion Alert	Transmitted when ground motion with a maximum seismic intensity of 5 lower or greater is predicted, to areas with a predicted seismic intensity of 4 or greater	JMA	Television, radio, mobile phones, etc.
4	Earthquake Information	A few seconds to a few minutes later	Seismic Intensity Information	Regional information on the ground motion that occurred	JMA	Television, radio, newspapers, and the JMA website
			Source Information	Information on the source and magnitude of the earthquake that occurred		

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3 Background and History of Development of the EEW System

3-1 Ground-Motion-Detecting Control

An idea of detecting ground motion immediately after an earthquake occurrence and controlling automatic shutdown of systems and the like had already been adopted by a number of systems before the development of the EEW. For example, in the case of a microcomputer meter that is commonly found in Japanese homes, a ground motion detector is installed within a gas meter, and when the sensor detects ground motion exceeding a specific level, the gas supply is instantly shut off automatically. Since Tokyo Gas Co., Ltd. introduced the system in the 1980s, it has come to be provided as standard equipment by gas suppliers nationwide including suppliers of propane gas.

Nuclear power plants employ a system to automatically shut down nuclear power reactors when a seismograph buried in the ground under the reactor core detects strong ground motion (about 200 gal). Recently, the Onagawa Nuclear Power Station went into an emergency shutdown from the 2003 Sanriku-Minami Earthquake (M7.1), the Kashiwazaki-Kariwa Nuclear Power Station from the 2007 Chuetsu-Oki Earthquake (M6.8), and the Hamaoka Nuclear Power Station from the 2009 earthquake in Suruga Bay (M6.5). In all of these cases, the automatic shutdown system functioned as expected. However, we need to be aware of the fact that the control rods for the shutdown were inserted amidst strong shaking.

Elevators, which are often used in our daily lives, also employ a function to automatically stop at the nearest floor when detecting ground motion. In reality, however, there are constant accidents where elevators stop upon an earthquake without the door opening, and people are trapped inside the elevators for many hours.

While these are three major examples, other original control systems are likely to be employed in various other scenes as well. If the level of the ground motion to be detected is set low, it will be possible for the control system to be effected by the arrival of the P-wave and to shut down the system before the arrival of the principal motion. Such system resembles the function of the EEW, but the EEW is superior in that it has the potential to initiate the response measure even before the arrival of the P-wave.

3-2 Prior case example: Development and performance of UrEDAS

The Urgent Earthquake Detection and Alarm System (UrEDAS) is a system for having trains come to an emergency stop at the time of an earthquake based on information sent from seismic observation points established along Japan Railways Shinkansen (bullet train) lines. It is the world's first system that materialized the concept of the EEW. UrEDAS, developed in the 1980s, experienced the first challenge at the time of the Chuetsu Earthquake on October 23, 2004 (M6.8). According to a developer, Yutaka Nakamura,[9,10] Joetsu Shinkansen Toki No. 325, which was traveling at a place 10-odd km in horizontal distance from the epicenter, received an emergency stop signal 2.5 seconds prior to the arrival of the principal motion, and stopped after traveling 1600 m from that point. As a result, although the train was derailed, it caused no casualties. The train is estimated to have slowed down by about 8 km per hour from the initial speed of 195 km per hour, during the 2.5 seconds. It is only a slight slowdown, but its effect cannot be ignored when a train is traveling at a high speed. It can be considered as the world's first example of a case where the concept of the EEW proved effective in a real situation.

3-3 Process toward development of the EEW

The Headquarters for Earthquake Research Promotion (HERP) of the Ministry of Education, Culture, Sports, Science and Technology, the establishment of which was prompted by the Hanshin-Awaji Earthquake Disaster, formulated "The Promotion of Earthquake Research: Basic comprehensive policy for the promotion of earthquake observation, measurement, surveys and research" (April 23, 1999)[11] as guidelines on research and development concerning earthquake countermeasures. One of the four basic measures indicated in this policy was *promotion of real-time transmission of earthquake information*, and development of the EEW was promoted under this measure. However, the concept of *real-time earthquake information* in this measure had placed more focus on ascertainment of the situation upon disaster occurrence, rather than the EEW. At the time, Hiroo Kanamori at the California Institute of Technology had advocated the keyword "real-time seismology." This was a study aimed at quickly analyzing the actual conditions of an earthquake that has already occurred, and ascertaining the extent and spread of damage on a real-time basis, thereby using such information for implementing disaster countermeasures that meet real needs. "Real-time" was adopted as a keyword in the measure above due to a serious regret that there was a delay in ascertaining the actual situation at the time of the Hanshin-Awaji Earthquake Disaster. In that sense, development of the EEW is likely to have been positioned as a task of secondary importance at the time of formulation of the measure. However, with the development of the digital strong-motion seismograph network (KiK-net) throughout Japan, the overall focus of "real-time research and development" gradually shifted toward practical implementation of the EEW.

Alongside such developments, the JMA was promoting development of Nowcast Earthquake Information based on a network of multifunctional seismographs at 200 locations nationwide, in response to Meteorological Council Report No. 21 (May 2000). Also, NIED was conducting development of Real-time Earthquake Information based on the Hi-net observation network of seismographs at 800 locations. Both of these projects had the same purpose as the EEW, which was to send information on earthquake occurrence at the earliest possible timing, and they were being promoted separately. Later, when development of the two projects reached a certain point, those projects were combined into a new project entitled "Research Project for the Practical Use of Real-time Earthquake Information Networks" (FY2003–2007),[12] which later gave birth to the Earthquake Early Warning. This project not only engaged in the development of EEW methodologies, but also in the new research field of how the EEW can be effectively used.

3-4 Developments overseas

Research, development, and operation of a system for issuing alerts immediately before ground motion, similar to the EEW, are also carried out in other countries, including the United States, Mexico, Taiwan, Rumania, and Turkey. In the United States,[13] Hiroo Kanamori et al., who have advocated real-time seismology, have indicated the potential of a system for issuing alerts immediately before ground motion, and have been calling for dissemination of such system, but such system has yet to enter into operation.

As discussed later, a system similar to the EEW is more effective against subduction-zone earthquakes than against inland earthquakes, so such system is drawing particular attention in Mexico and Taiwan that are located on subduction zones similar to Japan. In Mexico,[14] based on the lesson learned from the 1985 Michoacán earthquake (M8.0), Centro de Instrumentación y Registro Sísmico (CIRES; Center for Seismic Instrumentation and Recording)[15] launched operation of a system for issuing an alert immediately before ground motion called "Sistema de Alerta Sísmica de la ciudad de México (SAS)." This system has played the role of immediately issuing a notice of occurrence of a subduction-zone earthquake along the Pacific Ocean, to Mexico City, which is about 300 km away. During the four years of operation from August 1991, a total of 292 alerts were issued. At the time of an earthquake of M7.3 that occurred in September 1995, the notice was issued 72 seconds before the arrival of the principal motion. In Taiwan as well,[16] a system with a similar purpose called "Virtual Subnetwork" (VSN) is under operation, and alerts are issued to cities about 150 km away, with a time allowance of 20 seconds or more. This system has issued alerts for 54 earthquakes during a year-and-a-half period from December 2000.

In Romania,[17] an M8 earthquake is expected to occur at a depth of 150 km in the suburbs of Bucharest. To prepare for this earthquake, a proposal has been made to construct an Early Warning System (EWS) which can be expected to create a time allowance of 25 seconds. In Turkey,[18] an Istanbul Earthquake Rapid Response and Early Warning System (IERREWS) is proposed for creating a time allowance of 8 seconds, assuming earthquakes that occur on the Marmara Fault in the Istanbul suburbs.

In this way, systems for the same purpose are being developed or operated in various other countries, and their performance and effects vary depending on the regionality or the national characteristics. Among these, Japan's EEW system is considered to stand out in that it is based on precise analysis of information obtained from an exhaustive nationwide observation network.

4 Actual Status of Operation of the EEW

4-1 Advance Notices and Alerts

As mentioned above, EEWs issued in Japan are distinguished between Advance Notices and Alerts. While the distinction is based on the level of the target seismic intensity, the target recipients also differ as a result of the difference in their transmission methods. This difference also brings about difference in the basic characteristics between Advance Notices and Alerts. Simply put, the former are intended for expert users and the latter are for general users. Figure 3 shows their respective transmission methods.

An Alert is issued residents of target areas via television, radio, mobile phones, etc. when ground motion with a seismic intensity of 5 lower or greater is predicted. During a period of two and a half years until April 2010, a total of 14 Alerts were actually issued, including three Alerts for ground motion with a predicted seismic intensity of 6 lower or greater (the Iwate-Miyagi Nairiku Earthquake in June 2008; the Northern Iwate Intraslab Earthquake in July 2008; and the earthquake in Suruga Bay in August 2009). Meanwhile, there were five instances where an Alert was not issued although ground motion of seismic intensity 5 lower was observed. The reason was that, in all of these instances, the maximum seismic intensity was predicted to be 4. In an Alert, information on the seismic intensity distribution and the time allowance is omitted, and only the place name of the epicenter and the names of areas where strong ground motion is predicted to occur are reported.

An Advance Notice, on the other hand, is issued to business operators and individuals that have contracted with the Japan Meteorological Business Support Center, via dedicated terminals. The number of Advance Notices issued during the two and a half years until April 2010 totaled 1,391, which is quite a large number. This is because Advance Notices also cover predicted ground motion of M3.5 or greater, in other words, relatively small earthquakes. Among these, ground motion of seismic intensity 4 or greater was observed in 90 instances. Since an Advance

Notice includes information on the source, it is possible to customize the contents of the notice into more detailed information on seismic intensity by using such information. At present, however, a license from the Director-General of the JMA is required in order to provide such additional information. The number of licensed business operators as shown in Figure 3 is over 50 as of 2010.

4-2 Patterns of use of Advance Notices

Figure 3 shows various fields of use as sectors to which Advance Notices are sent. In these sectors, users are assumed to use earthquake information as professionals in the respective fields.

The Research Project for the Practical Use of Real-time Earthquake Information Networks introduced in Section 3-3 positioned effective use of Advance Notices as one of its research tasks. In order to pursue this research task, an incorporated nonprofit organization, the Real-time Earthquake Information Consortium (REIC), was established. REIC has focused on 14 fields, including the following: fire and disaster prevention; disaster prevention sites; medical care; in-home automatic control; power-generating stations and factories; communications; schools; dams; FM character multiplex tuners; LPG automatic shutoff; and building facilities. For these fields, REIC has promoted development of specific methods for effectively using Advance Notices, in cooperation with technical experts engaged in disaster prevention projects in the respective fields.[19, 20]

Uses of Advance Notices can roughly be divided into two major types. One is automatic control using the signals from dedicated terminals. For example, elevators are equipped with a ground-motion-detecting control system, but still, there have been a constant number of incidents where people are trapped in elevators as a result of ground shaking from an earthquake. An expectation that use of Advance Notices, which have the potential of controlling elevator operation before shaking, will contribute to reducing the number of such incidents is one of the most clear-cut effects of Advance Notices. Advance Notices are issued for ground motion of seismic intensity 3 or greater. Such level of shaking does not pose a problem in everyday life, but it has the possibility of inducing accidents at constructions sites, particularly in crane operations. Also, in precision processing factories and data centers, even slight shaking could cause misalignment or data deficiency leading to substantial economic loss. In that sense, automatic control, such as automatic shutdown, based on Advance Notices is likely to prove useful in many instances.

The other type of use is where Advance Notices cannot be used for automatic control, but can be used as meaningful information. For example, for a doctor attending surgery in a hospital, an advance notice of soon-expected shaking would be extremely valuable for allowing him/her to prepare for the shaking. Such instances are expected to potentially exist also in fields other than those shown in Figure 3. An important point is that, in both types of uses, the target recipients of Advance Notices are professionals in the respective fields. Although it is possible for individuals to receive Advance Notices, Advance Notices basically assume the recipients to be capable of taking appropriate measures. Therefore, the recipients are required to have professional awareness and sense.

4-3 Effects of Alerts

While Advance Notices target professionals, Alerts target the general public. The JMA website provides information on how to respond to an Alert according to six scenariossuch as at home or outside.[6] However, it is considered to be difficult in actuality to promptly respond to an Alert in such different ways according to the scenario. The general public cannot be treated in the same manner as professionals from whom training achievements can be expected. Many people are likely to be surprised by a sudden alert, unable to move not knowing what to do. Although such response is generally considered to be undesirable according to an instruction manual[19] and other documents, the author does not necessarily think so. As in the example of lightning mentioned in the beginning of this article, people may be unable to move, but at least at that moment they would be able to prepare themselves for what is about to come.

When ground motion of seismic intensity 5 lower or greater is predicted at any one location, an Alert is issued to all areas where ground motion of seismic intensity 4 or greater is predicted. Consequently, the level of shaking experienced by the recipients in most locations would be about seismic intensity 4. Ground motion of seismic intensity 4 hardly causes any substantial damage, but according to the author's experience, people would suffer considerable

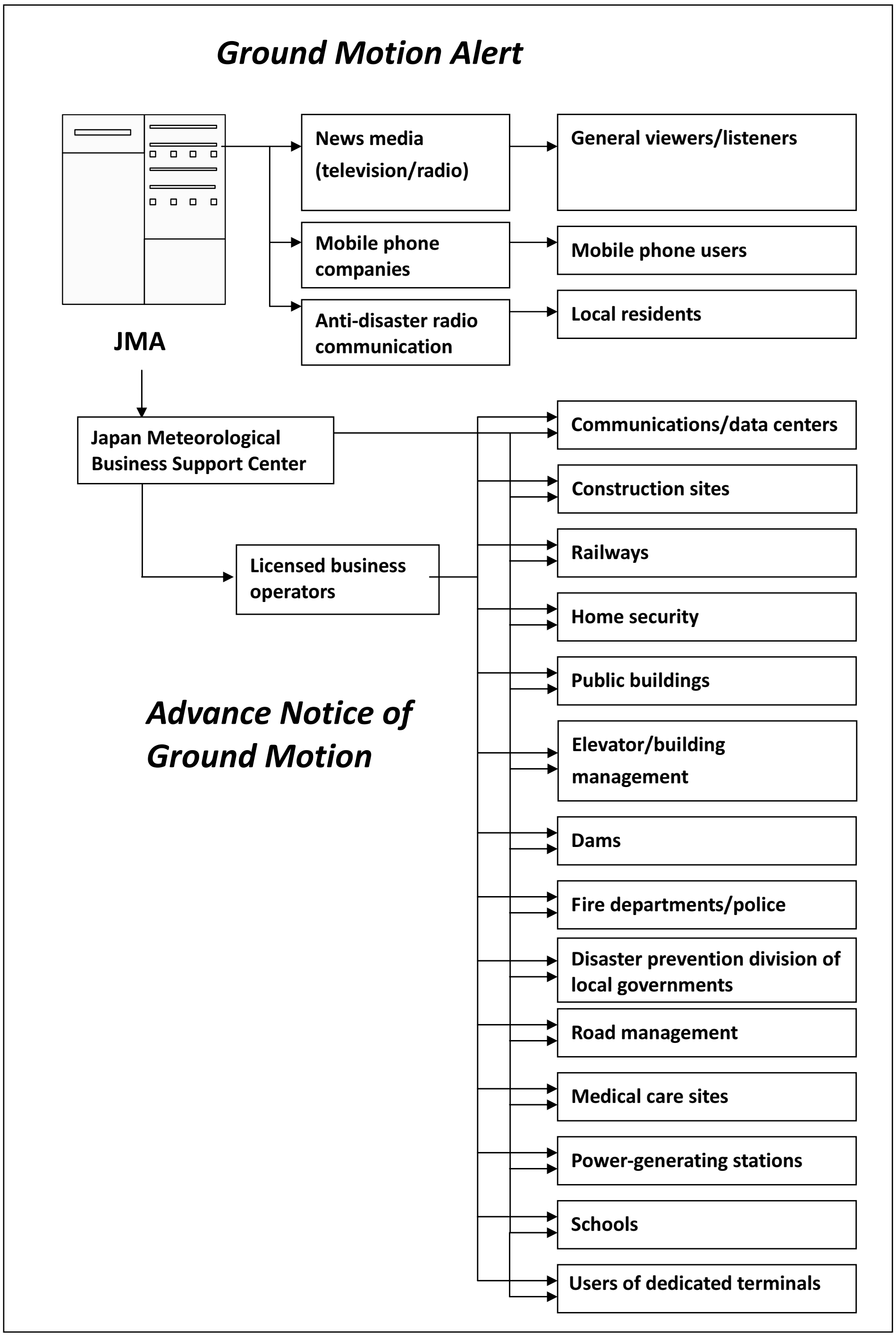

Figure 3 : Transmission Patterns of Earthquake Early Warnings

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psychological fear when such level of shaking occurs. It is because we do not know how large the sudden shaking will swell. In such an instance, if information on the maximum seismic intensity in each area is issued in advance, it is likely to have sufficiently high psychological effect against such fear. While the current Alert does not include information on the predicted seismic intensity, whether or not such information should be included would be one of the issues to be studied in the future.

The most problematic case assumable for receiving an Alert is at the time of driving a car. This is an instance where the general public is required to make a response as a professional. The JMA presents three instructions including "do not quickly brake," but since the circumstances would differ for each and every driver, it would remain a difficult problem in the future.

5 Problems of the EEW and the Direction for Improvements

5-1 Regressiveness between seismic intensity and time allowance

As mentioned in the introductory section, the EEW involves regressiveness whereby the time allowance becomes shorter as the seismic intensity becomes larger. This phenomenon is explained below using graphs. Figure 2 indicates a time chart for arrival of the first report to a location with a source distance of 30 km, but here, the seismic intensity is not taken into consideration in making the estimation. Figure 4 shows the time relation between the S-wave arrival time and transmission of the first report (the shaded portions in the lower part of the graphs) for areas where the seismic intensity will be 4, 5 lower, 5 upper, 6 lower, and 6 upper, according to the respective earthquake magnitudes. The time difference between the S-wave arrival time and transmission of the first report is the time allowance. This estimation directly applies the attenuation relation of ground motion and the source area evaluation method used by the JMA. The left graph shows the case of an inland earthquake, and the right graph shows the case of a subduction-zone earthquake. The assumed source depth is 10 km, and the horizontal distance to the nearest observation point is set at 10 km for the inland earthquake, and 50 km for the subduction-zone earthquake. The site amplification factor is assumed to be 1.0, and, based on a report by the JMA, the first report is assumed to be transmitted 5.5 seconds after the detection of the P-wave.

These graphs reveal that, where the seismic intensity is identical, the time allowance becomes longer as the magnitude becomes larger, that is, as the earthquake becomes larger. On the other hand, when the magnitude is fixed, or, when focusing on a single earthquake that has occurred, regressiveness is observed whereby the larger the seismic intensity the shorter the time allowance is.

According to the JMA document "Relation Between Instrumental Seismic Intensity and Damage, etc.,"[21] serious damage such as destruction of buildings occurs when the instrumental seismic intensity is about 5.5 or greater, that is, when the seismic intensity is 6 lower or greater. This also applies to buildings built in or before 1981, the year in which the Building Code was enacted. For example, in the left chart in Figure 4, where the magnitude is M7.2, the S-wave arrives at the outermost edge of the area with seismic intensity of 6 lower 11.6 seconds after the earthquake occurrence, and the first report is transmitted 8.5 seconds after the earthquake occurrence, generating a time allowance of about 3 seconds. Even for the same earthquake, in an area with seismic intensity of 4,

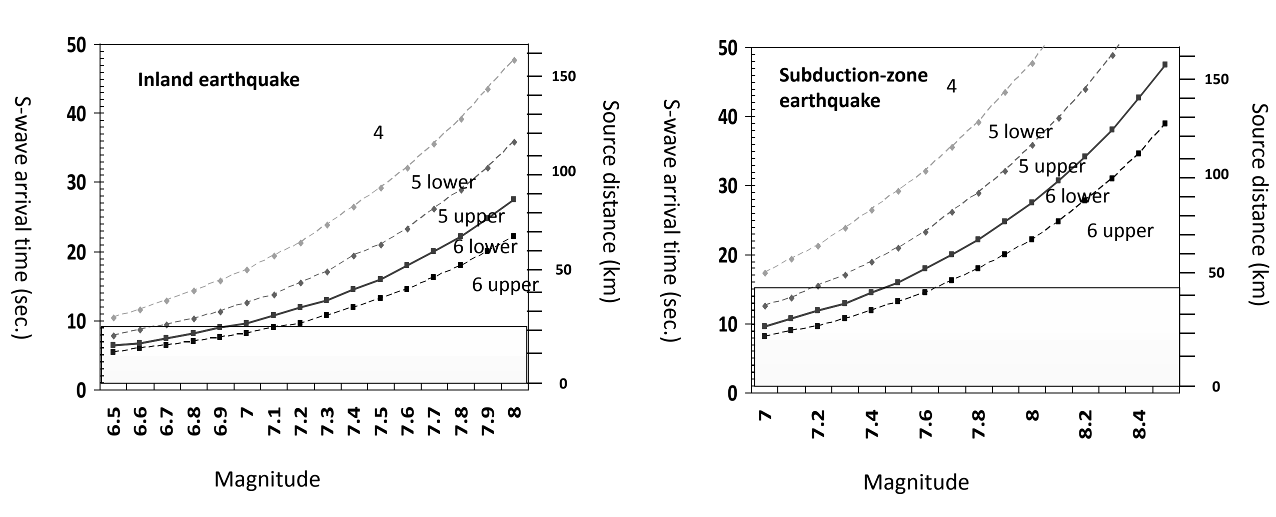

Figure 4 : S-wave Arrival Time by Seismic Intensity
Left graph: inland earthquake (source depth: 10 km; horizontal distance to the nearest observation point: 10 km; and site amplification factor: 1.0)
Right graph: subduction-zone earthquake (source depth and horizontal distance: same as above; and horizontal distance: 50 km)
Shaded portion: time elapsed until the transmission of the first report (Any portion beyond this shaded portion represents a time allowance.)

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the S-wave arrives 21.3 seconds after the earthquake occurrence, so there will be a time allowance of 12 seconds or more. Figure 5 shows the distribution of time allowance and seismic intensity for the actual case of the Iwate-Miyagi Nairiku Earthquake (M7.2) on June 14, 2008. The figure reveals that the distribution more or less coincides with the estimation in Figure 4.

Since 1900, earthquake disasters causing deaths of 10 or more persons have occurred 36 times in

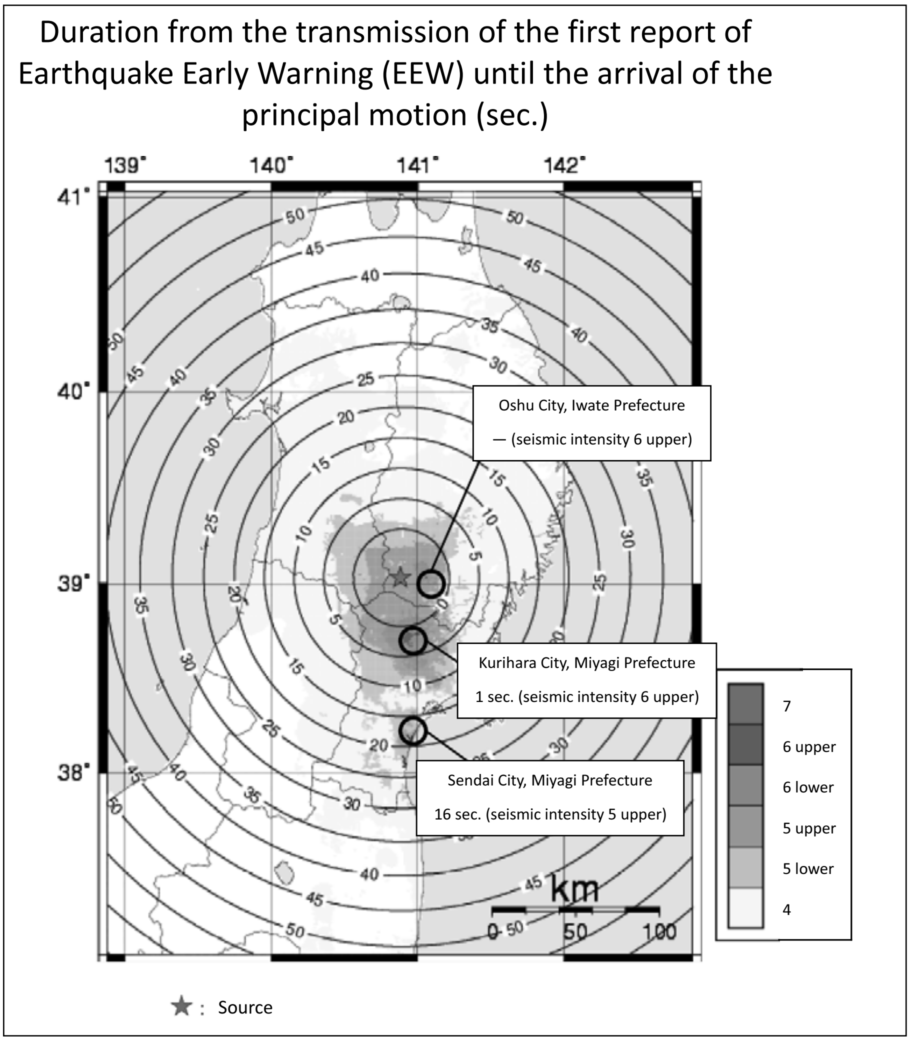

Figure 5 : Actual Example of the EEW Issued for the 2008 Iwate-Miyagi Nairiku Earthquake (M7.2)

Source: JMA[7]

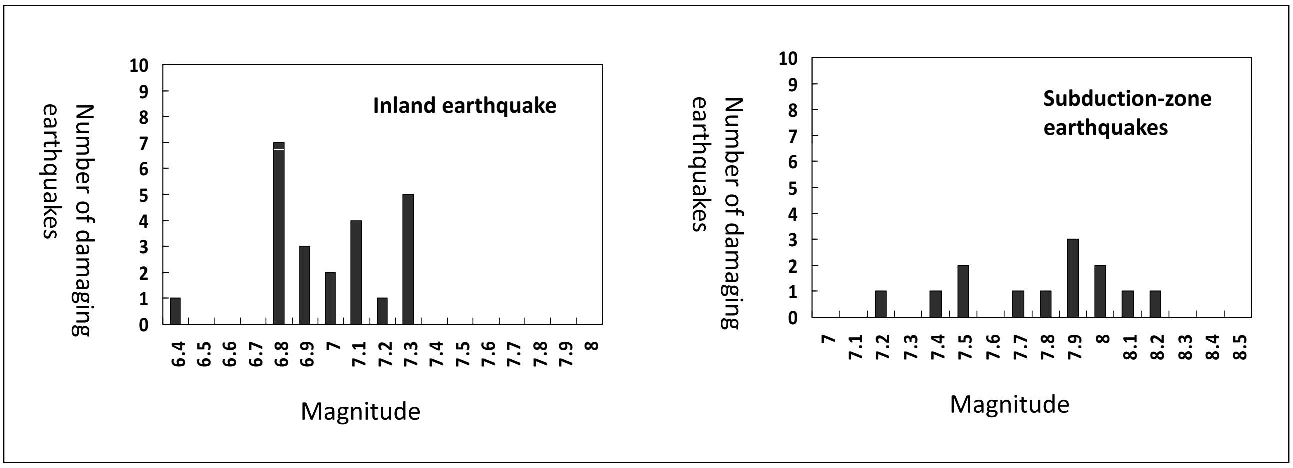

Figure 6 : Number of Damaging Earthquakes Causing Deaths of 10 Persons or More Since 1990
Left graph: Inland earthquakes
Right graph: Subduction-zone earthquakes (including earthquakes along the eastern margin of the Japan Sea)

Prepared by the STFC

Japan, including the 1995 Hanshin-Awaji Earthquake Disaster (M7.3) which caused a large-scale disaster recently. Figure 6 classifies such earthquake disasters into those of inland earthquakes (left graph) and those of subduction-zone earthquakes (right graph), and indicates the respective distributions of magnitudes (earthquakes that have occurred along the eastern margin of the Japan Sea are included in subduction-zone earthquakes). The average magnitude of the 23 inland earthquakes was M7.0±0.2. According to Figure 4, when the transmission delay is taken into consideration, there would hardly be any time allowance for ground motion with a seismic intensity of 6 lower or greater caused by these earthquakes. Therefore, even if an Alert had been issued for these earthquakes, it is questionable whether it would have had an effect to reduce the number of deaths.

On the other hand, the average magnitude of the 13 subduction-zone earthquakes was M7.8±0.3, and even for ground motion with seismic intensity of 6 lower or greater, a time allowance exceeding 10 seconds would be generated depending on the place. The right graph in Figure 4 has assumed the horizontal distance from the nearest observation point to the source to be 50 km, but if a seismograph is installed on the seafloor near the source, the time allowance would be even longer. Figure 7 indicates the positions of cabled seafloor seismic observation points where observation has already been implemented. They are all located along the Pacific Ocean, such as off

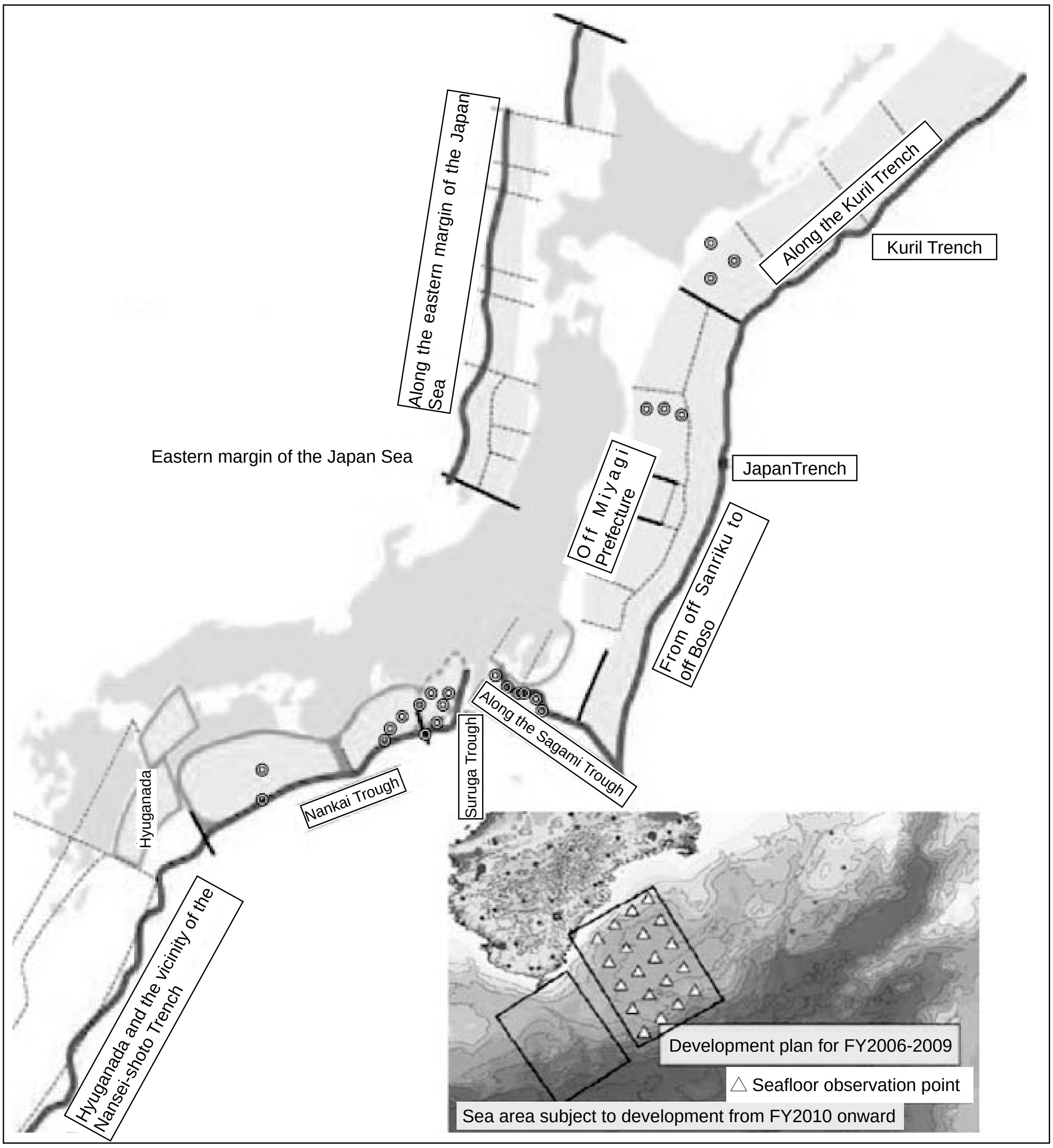

Figure 7 : Assumed Subduction-zone Earthquakes and Cabled Seafloor Seismographs (◎)
Bottom right figure: the Dense Oceanfloor Network System for Earthquakes and Tsunamis being developed by JAMSTEC in Kumanonada for Nankai Trough earthquakes
Prepared by the STFC based on documents of HERP[22] and JAMSTEC[23]

Kushiro, off Sanriku, Sagami Bay, Enshunada, and off Cape Muroto. A particularly notable location is off Kii Peninsula. This location is predicted as becoming the source of Tonankai-Nankai Earthquakes in the near future, and as shown in the bottom right figure in Figure 7, a massive-scale, seafloor seismic observation network is currently being developed there by the Japan Agency for Marine-Earth-Science and Technology (JAMSTEC).[23] Therefore, Alerts can be expected to fully demonstrate their intended function for such subduction-zone earthquakes.

5-2 Challenges of the prediction techniques and improvement efforts

Continued improvement efforts are being made for the currently operated EEW. The key point of improvement is to raise the accuracy of the predictions.

While the first report is information that has been analyzed by using only the P-wave signal received at the nearest observation point, techniques called the level method[5] and the B-Δ method[5] are currently used in order to presume the source. The level method sends out information at the point when strong motion of 100 gal or more is detected. It hardly requires any processing time, but information from multiple observation points would be necessary in order to conduct source analysis. On the other hand, the B-Δ method conducts source analysis based only on information from a single observation point. Since source analysis involves a total of five unknown values including the location, the origin time, and the magnitude, it is basically extremely difficult to determine all of these values based on information from only a single observation point. However, the B-Δ method manages to promptly provide source information while supplementing lacking information by an ingenious approach, which is to determine the direction from which the wave has arrived based on signals of three components, and to determine the location of the source by presuming the distance using the waveform characteristic that the farther the earthquake is, the higher the scattered wave component will be. Furthermore, by using techniques that also consider information such as that the seismic wave has not arrived at surrounding observation points, such as the territory method,[5] the grid search method,[5] and the arrival/non-arrival method,[24] quite accurate information on the source location can be obtained within an extremely short time even at present.

In contrast, it is difficult to infer the magnitude. Although the magnitude is generally determined by using information on the entirety of seismic waves, in the first report the magnitude needs to be inferred based only on the start portion of the P-wave. As a result, the predicted seismic intensity inevitably contains a certain extent of error or uncertainty. While the magnitude is supposed to be determined based on the maximum amplitude of all phases of seismic waves, the magnitude value in the first report of the EEW is calculated based only on the first three seconds of the waveform of the P-wave. If the slip velocity on the fault plane is assumed to be 1 m/sec., earthquakes with a maximum slip of 3 m, that is, earthquakes of up to M7.5, can be evaluated. Also, if the rupture propagates, or, if the fault plane grows at the S-wave velocity, correct evaluation can be made for earthquakes with a maximum fault length of 20 km, that is, earthquakes of up to M7.0. Due to these limitations, the magnitude cannot be correctly evaluated in the EEW for a large earthquake of the M7 class or greater. Although the estimated value of the magnitude is updated by the second report and the third report along with the growth of the seismic waves, there is an unavoidable problem that the magnitude in the first report tends to be underevaluated in the case of a large earthquake. Over the past two and a half years, the predicted seismic intensity did not reach the Alert standard in five out of the 19 cases where ground motion of seismic intensity 5 lower or greater was actually observed. This problem is regarded as a particularly important challenge to be addressed in improving the EEW. Various new techniques have been proposed, but the mutually opposing nature of instantaneousness and accuracy remains until the end.

Similarly, identification of the source area of a massive earthquake is another important challenge. The rupture of an earthquake does not remain in the vicinity of the source, but for example, in the case of an M8 earthquake, a source area exceeding 100 km will be ruptured, spreading even to a location far away from the source which could be hit by ground motion of seismic intensity 6 class. The current analysis technique makes approximate calculation using the distance from a sphere of a size corresponding to the magnitude, in place of the source distance, but the calculated distance using this method will deviate more substantially from the actual distance as the earthquake becomes larger. Accordingly, a number of techniques have been devised for instantly identifying the source area. Although constant efforts are made to raise the accuracy of the EEW, the difficulty of handling larger earthquakes and the scarcity of the opportunities for actual verification are serving as barriers in research.[25]

As mentioned earlier, the EEW is expected to demonstrate its function most effectively for subduction-zone earthquakes. Among them, the major target would be the next Tonankai and Nankai Earthquakes, which are the largest-scale subduction-zone earthquakes. The current EEW is a *general-purpose* EEW targeting all earthquakes that clear the standards. Apart from this, however, it may be necessary to consider a *special* EEW that premises a special analysis method and a special reporting method that exclusively target the Tonankai and Nankai Earthquakes.

5-3 Approach from users' viewpoint

As discussed above, the Advance Notice is a service intended for expert users. Licensed business operators who have been approved by the Director-General of the JMA may add information which they have originally analyzed based on the information provided by the JMA. Particularly important additional information would be more precise seismic intensity based on detailed ground information. The JMA's predicted seismic intensity is based on ground information that has been averaged for a large area of about 10 km square, but actual ground conditions differ by each small land area, and it is no exaggeration to state that the conditions could even differ by each building site in some places. In the case of a high-rise building, the seismic intensity would differ by each floor. Thus, a company distributing Advance Notices will be able to differentiate their service from those of competitors by providing information that reflects individual customers' specific conditions. In this manner, the key to success of the business of providing Advance Notices would be to precisely respond to individual users' slightly differing needs for Advance Notices.

The frequency Alert issuance represents only about 1% of Advance Notice issuance. Nevertheless, the Earthquake Early Warning has become so well-known among the general public largely due to the transmission of Alerts. Conversely, people's opinion on Alerts tends to directly become their opinion of the EEW. Taking a look at news reports over the two and a half years since the launch of operation of the EEW from such perspective, the author receives an impression that mass media as well as people concerned in the EEW development focus too much on a single point—whether or not the EEW managed to reach recipients in time for the principal motion. As long as the function of issuing information immediately before ground motion is regarded as the biggest draw of Alerts, it is unavoidable that people's attention tends to be directed only to this point. As a matter of course, continued attempts should be made to extend the time allowance by working toward improving the analysis techniques and systems. However, such efforts cannot go beyond the limits of principle. Now that the Alert has outgrown its novelty, it is considered to be the time for thinking about realistic measures for using the Alert. For example, for near-field earthquakes where no time allowance can be expected, it would be better to shift the focus to the real-time nature of the Alert, rather than continue pursuing whether or not the Alert can be issued in time for the principal motion. This means to treat the Alert as part of ground-motion-detecting control systems. Ground-motion-detecting control systems have been used in various fields since before the introduction of the Alert, but now that the Alert is penetrating into society, it may be possible to introduce *control by the Alert* as a new usage. One such idea is to distribute control signals triggered by the Alert to each home by taking advantage of the digitalization of televisions.

At the same time, there are fields where general-purpose use of the Advance Notice and the Alert is unsuitable. An extreme example is a nuclear power reactor. Nuclear power reactors already have a ground-motion-detecting control system, but there are too many problems involved in applying *control by the Advance Notice or the Alert* to the system, at least at present. In such a case, it would be more desirable to construct an original control system for the reactor based on the concept of the EEW; that is, to install seismographs for the current ground-motion-detecting control system at distant locations from the reactor. In actuality, a scheme is already taking shape to install a seismograph network surrounding a reactor as well as to install seismographs at the bottom of wells of several thousand meters deep in order to gain a time allowance of around 2 seconds for inserting the control rods.

5-4 Improvement of the Tsunami Warning as a ripple effect

Development of the EEW is expected to promote improvement of the Tsunami Warning as a ripple effect. The Tsunami Warning, which was introduced based on the Meteorological Service Act of 1952, reached the level of a practical warning through its computerization in 1980. However, in the subsequent 1983 Nihonkai-Chubu Earthquake (M7.7) and 1993 Hokkaido Nansei-oki Earthquake (M7.8), the warning failed to reach coastal residents in time, and the number of deaths and missing persons combined reached 100 and 259, respectively. Since source locations along the Sea of Japan are close to the coast, tsunamis arrive in a very short time after earthquake occurrence. In the case of the Nihonkai-Chubu Earthquake, a tsunami arrived 7 minutes after the earthquake occurrence at the quickest, and in the case of the Hokkaido Nansei-oki Earthquake, 3 minutes after.[26] However, as short as it is, the arrival time is in the order of minutes, so compared with the fact that the EEW is dealing with a time allowance in the unit of seconds, the technical barrier is considered to be lower. The effects of improvements relating to quicker issuance of the EEW, including the reliability of the receipt, analysis, and communications of data, contribute to quickening the issuance of the Tsunami Warning, and such improvements of the Tsunami Warning are under way.

6 Summary

At the time when the EEW was introduced in society, there was a trend to regard the EEW as a business opportunity. At present, however, an analysis has even been made that many companies have withdrawn from the service of providing the EEW, and this has left a negative impression that disaster prevention business involves substantial risk.[27] On the other hand, it is a fact that the EEW has been welcomed by society as one of the few case examples in which seismic research achievement has been directly put to beneficial use in people's lives, and that the EEW has been penetrating into people's daily lives. With the actual conditions of the EEW gradually becoming clear, EEW businesses are entering a crucial stage where their viability will be tested. Indeed, a system using dedicated terminals with built-in seismographs has been developed and commercialized, taking advantage of the weakness of the EEW that it cannot reach the user in time in the case of a near-field earthquake.

In the same sense, while the EEW has received high expectations as if it will become the core of future earthquake disaster prevention measures,[28] there is a concern that expectations could swell excessively. It has been the norm for conventional disaster prevention measures that such expectations tend to overestimate the measure, and generate a large gap with the reality. It is natural in a sense that expectations grow in the development phase, but when the EEW has been operated to a certain extent, it needs to be evolved into a realistic measure based on its actual performance, while considering the significance and limits of the EEW. The following list summarizes the author's main opinions and proposals mentioned in this article with focus on the realistic positioning of the EEW.

(i) The Alert and the Advance Notice differ only in terms of the target scope of predicted seismic intensity, but the difference in their recipients (the general public or expert users) creates a large difference in the nature, effect, and usage of their information. When discussing the EEW, these two need to be considered separately.

(ii) The EEW involves regressiveness whereby the time allowance becomes shorter as the seismic intensity becomes larger. In actual instances, many people may experience that they could deal with ground motion with a seismic intensity of 4 due to receiving the Alert. The author holds a concern that such experience would lead to an established impression that such effect is always guaranteed.

(iii) Since the EEW has only been operated for two and a half years, it has not yet encountered an event where it could fully demonstrate its intended function. Through accumulation of experience, users in their respective standings need to learn the most effective use of the EEW, while understanding its characteristics and limits. Also, information on seismic intensity is extremely meaningful in the process where EEW recipients accumulate experience and deepen their understanding. Although the current Alert omits information on seismic intensity, it is desirable to also include information on predicted seismic intensity distribution while giving consideration on how it should be conveyed.

(iv) Serious damage that causes casualties generally occurs when the seismic intensity is 6 lower or greater. Although there are exceptions, in the case of an inland earthquake, the EEW cannot reach the recipients in time for ground motion with such seismic intensity. However, in the case of a subduction-zone earthquake, the EEW could generate a time allowance of 10 seconds or more. In particular, high expectations are held for the EEW's effect for the next Tonankai-Nankai Earthquakes for which a seafloor seismic observation network is being developed. It may be significant to develop different EEW specializing in these particular earthquakes.

(v) In the case of a large subduction-zone earthquake, not only the near-field ground motion, but also the long-period ground motion in distant alluvial plains and sedimentary basins, particularly the Kanto Plain, becomes a problem. Research on disasters caused by long-period ground motion has only been started, but in such a case, the EEW which can generate a time allowance of several tens of seconds is expected to demonstrate a substantial disaster mitigation effect.

(vi) Mass media and people concerned in the EEW development focus too much on whether or not the EEW managed to reach recipients in time for the principal motion. Even in the case where the EEW does not reach the recipients in time, attention should be paid to the real-time nature of the Alert, in other words, that the Alert is transmitted almost at the same time as the earthquake occurrence. The current Alert does not employ the concept of automatic control, but in the sense of complementing the weakness of the Alert that it cannot reach the recipients in time for the strong ground motion of an inland earthquake, it may be necessary to adopt the concept of *control by the Alert* in the future.

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Profile

Shozo MATSUMURA
Senior Expert Researcher, National Institute for Earth Science and Disaster Prevention
http://www.bosai.go.jp/

Doctor of Science (Dr. Sc.). Dr. Matsumura's specialty is seismology. His aim is to detect precursory phenomena preceding major earthquakes by observing microearthquakes. He is particularly interested in understanding the condition of stress redistribution generated by slow slip and quasi-static slip from changes in patterns of seismic activity, focusing on Tokai earthquakes. He is an Expert Member of the Headquarters for Earthquake Research Promotion.

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5

Have Past Foresight exercises been able to correctly indicate future directions?

Yoshiko YOKOO
General Unit

1 Introduction

In Japan, foresight exercises have been conducted every five years since 1971, to gain perspectives on future trends in science and technology in view of the coming thirty years. The National Institute of Science and Technology Policy (NISTEP) has been responsible for the task since the fifth Foresight , and has extended the objectives to provide the future outlook of science and technology as well as the future society surrounding it, and in recent years added the grasping of social needs and the drawing up of future scenarios. The latest exercise in FY 2009, "The 9th Foresight : Contribution of Science and Technology to Future Society," was conducted with a picture of the future direction to pursue borne in mind, whereby the focus of discussion was placed on methods to overcome the global and national issues that may arise in the future .

The exercise included: a questionnaire for experts, on the development of science and technology; a scenario of people's lives in the future, and a framework and paths that would lead to such a scenario; and workshops to enable discussion on each region's sustainable development and its enabling technologies. The results were compiled into a three-volume report.[1]

The questionnaire for experts (Delphi survey) has been conducted from the first Foresight to the latest, with no exceptions, enabling us to evaluate the reliability of the predictions, i.e., the level of attainment viewed from the present perspective.

The predictions from the first Delphi survey, which was published in 1971, to the fifth (published more than twenty years after the 1st, in 1992) have been assessed by groups of experts. As Japan is the only country in the world that has carried out uninterrupted surveys of this kind, it has the unique opportunity to examine the wisdom of the past, and the surveys may be considered as a valuable soft-asset from a global perspective.

An announcement of the survey evokes an interest in how many of the past predictions have been realized and to what degree. This report presents an overview of the realization assessment covering the predictions of the first to fifth surveys, and gives an account of some science and technology that has been realized and some that has not come to fruition.

2 The Method for Assessing the Realization Status

The questionnaire, for experts, on individual fields of science and technology is named after the method employed, and hence is called the Delphi survey. The Delphi method is to implement two or more rounds of the same questionnaire for a group of experts, until the answers converge towards some concrete opinion. In the second and subsequent rounds, summary results of the previous round are shown to the respondents, and they are encouraged to review their early answers in light of the trends of the overall opinions. As some respondents modify their views and adopt the mainstream ideas, the overall opinion tends to converge (Table 1). The Delphi method is considered to be one of the effective methods for long-term foresight, which has to depend more or less on intuition.

Delphi surveys thus far conducted in Japan have included two rounds of the questionnaire for the purpose of gathering experts' opinions on future science and technology ("topics" in this report) in terms of the importance, feasibility, and the approach to be taken for realization. In the fifth Delphi survey, an evaluation of the results of the first Delphi survey was implemented in order to assess the realization status. Thus, one previous survey has been added at the time of each Delphi survey since the fifth one.

A summary of the five previous Delphi surveys , whose realization statuses were assessed in the ninth Delphi survey, is shown in Table 2. From the first to the fifth survey, the number of topics taken up became larger and larger, as did the number of respondents. Also, topics concerning the fundamental aspects of science and technology have gradually become included in the surveys, in addition to the technologies of significance in view of social applications.

The work for the realization status assessment carried out in the ninth Delphi survey was allotted to twelve panels, which were organized for the ninth survey. Preliminary counseling decided that the levels of realization of these topics should be classified, based on the evaluation from the viewpoint at the time of assessment, into the following three levels: “fully realized,” “partially realized,” and “not realized.” Partial realization includes cases where some of the contents of the topic have been realized and cases where the results open to consideration show that realization has been reached from some viewpoints, but not from all. For the topics judged as “not realized,” the reasons for no realization were also discussed. Although the survey results include information on the expected year of realization, there are cases where pinpointing the precise period of realization is difficult. Therefore, a comparison of the years of expected and actual realization was not performed.

3 Overview of Realization Status Assessment

The following is an overview of the realization status as of the time when the ninth Delphi survey was conducted. Further details can be found in the reference materials of the ninth Delphi Survey Report.[1]

3-1 Ratio of Realization

The assessment indicates that around 70 percent of the topics given in the first through fifth surveys have been realized (including partial realization) (the number of realized topics / the total number of target topics). The ratio of exact realization increases with time. However, the ratio for the other 30 percent of topics does not increase with time, indicating that it is impossible to realize these topics in the time span of tens of years, or that they have become obsolete or meaningless over time.

Field-by-field examination indicates that the fields directly related to human life (e.g., environment,

Table 1 : An Example of a Delphi Survey Summary Sheet

*The pentagons in the table represent the middle one-half of responses on the time of realization (the left edge, central apex, and right edge represent the 1/4, 1/2, and 3/4 accumulation points of the responses, respectively, arranged in order of forecasted year of realization [from early to later]). The hatched pentagon represents the results of the second round of the questionnaire, indicating a converging tendency of the opinions (i.e. narrower width than the non-hatched pentagon, which represents the first round). The apex of the shape (i.e. the halfway point of the accumulated responses arranged in order of realization year — from earlier to later years — is used as the value representing the year of realization.

Classification	Topic number	Topic	Questionnaire	Number of respondents	Forecasted time of technological realization (The period when the topic will be realized somewhere in the world)								Forecasted timeof social realization (The period when the topic will become applicable/widely used in Japan)							Main organization/sector that promotes social realization (left columns)					
					Has already been realized	2011 - 2015	2016 - 2020	2021- 2030	2031 - 2040	2041 or later	Not realizable (%)	I don't know	2011- 2015	2016 - 2020	2021 - 2030	2031 - 2040	2041 or later	Not realizable (%)	I don't know	University (%)	Public research organization	Private enterprise (NPO included)	Government (local government included)	Alliance of multiple fields	Others (ex. International organization)
Mechatronics	65	A supporting robot for human lives and activities (such as nursing care and domestic affairs) in general households.	1	165							0	1						0	2	23	27	72	21	36	3
			2	145							0	1						0	2	15	23	80	16	33	1
			Expert	12							0	0						0	8	33	33	92	0	25	0
	66	Autonomous robots with a judgment function that is capable of coping with complicated situations, such as production process work with process changes or situations like farm work	1	143							0	3						0	4	24	27	77	16	32	1
			2	127							0	2						1	3	20	26	84	10	28	2
			Expert	11							0	0						0	0	36	36	91	0	9	0

Source: Reference[1]

Table 2 : Implementation Summary: First to Fifth Delphi Survey

Survey No. (year)	Area under investigation	Time scope (30 years)	Number of topics	Questionnaire responses
1st (1971)	(1) Social development (enhancement of living standards [clothing, food, and housing], leisure, urb an development, (2) Information, (3) Medical insurance, (4) Food and agriculture, (5) Industry and resources (exploitation/development of space/ocean/energy/resources, upgrading of mining and manufacturing, development of new materials).	Up until 2000	644	2482
2nd (1977)	(1) Resources and energy (food/forest/water resources and energy), (2) Environment and safety (environment and safety), (3) Family life and education (domestic life, leisure, and education), (4) Health (health care, medical care, and labor), (5) National land-use (transport, information and construction), (6) Industrial manufacturing, (7) Advanced/fundamental science and technology (space/marine exploratation, life science, and soft science).	Up until 2005	656	1316
3rd (1982)	(1) Energy and mineral/water resources, (2) Agricultural/forestry resources, (3) Life and education, (4) Environment and safety, (5) Health/medical care, (6) Life science, (7) Cities, construction, and civil engineering, (8) Traffic and transportation, (9) Communication, information, and electronics, (10) Space, (11) Marine science, (12) Materials and devices, (13) Manufacturing and labor.	Up until 2010	800	1727
4th (1987)	(1) Material, and processing, (2) Information, electronics, and software, (3) Life science, (4) Space, (5) Marine science, (6) Earth science, (7) Agriculture, forestry, and fishery, (8) Mineral/water resources, (9) Energy, (10) Manufacturing and labor, (11) Health/medical care, (12) Life, education, and culture, (13) Transportation, (14) Communication, (15) City and construction, (16) Environment, (17) Safety.	Up until 2015	1071	2007
5th (1992)	(1) Material and processing, (2) Information and electronics, (3) Life science, (4) Space, (5) Elementary particles, (6) Marine/earth sciences, (7) Mineral/water resources, (8) Energy, (9) Environment, (10) Agriculture, forestry, and fishery, (11) Manufacturing, (12) Cities, construction, and civil engineering, (13) Communication, (14) Traffic, (15) Health/medical care, (16) Social life.	Up until 2020	1149	2385

Source: Reference[1]

security, health care, medicine, and life science) have a relatively high score in terms of the realization and partial realization rate. The ICT field shows a high score for the exact realization ratio (excluding partial realization). On the other hand, the fields related to transport and energy show low ratios of realization. As a general tendency, those topics that were expected for early realization scored high realization ratios, and those with a lower degree of importance generally show low realization ratios. Note, however, that there have been some cases where topics with low importance were realized, notably in the in ICT field.

3-2 Reasons for No Realization of a Topic

Inspecting the reasons for no realization of a topic, technical problems are by and large the most frequent causes.

In the first and second surveys, where many of the topics involved social aspects, a relatively large portion of the reasons for no realization was occupied by social problems and insufficient needs. However, each time the survey was conducted, the proportion of technical problems cited as the obstacle to realization has become progressively larger.

As viewed on a field-by-field basis, technical problems have been cited as the reason for no realization in more than 75 percent of topics related to medical and health care through the first to fifth surveys. Cost is one of the major problems, in addition to technical problems, in infrastructure-related domains, such as resources and energy, transport, construction and civil engineering, and the frontier domains, such as space and marine. Cost is the most frequently cited obstacle in some cases. The advent of alternative technology is also pointed out as the obstacle more often in fields related to ICT or electronics (especially in communication field) than in other fields. In the fourth and fifth surveys, among the topics that failed to be realized, for around 30 percent of them, the advent of an alternative technology was stated as the reason for no realization.

As an example, the obstacles to realization of the topics in the fifth survey, are shown for each field in Figure 2. Among the 100 most important topics that were predicted to be realized by 2009, some of them still remain unrealized, and the reasons why are listed in Table 3.

4 Examples: Realized and Unrealized topics

This section introduces selected examples of realized and unrealized topics listed through the first to fifth survey. The characteristics of the Delphi survey and subsequent developments of the topics are also described. Note that the "partially realized" cases are included in the description of the realized topics.

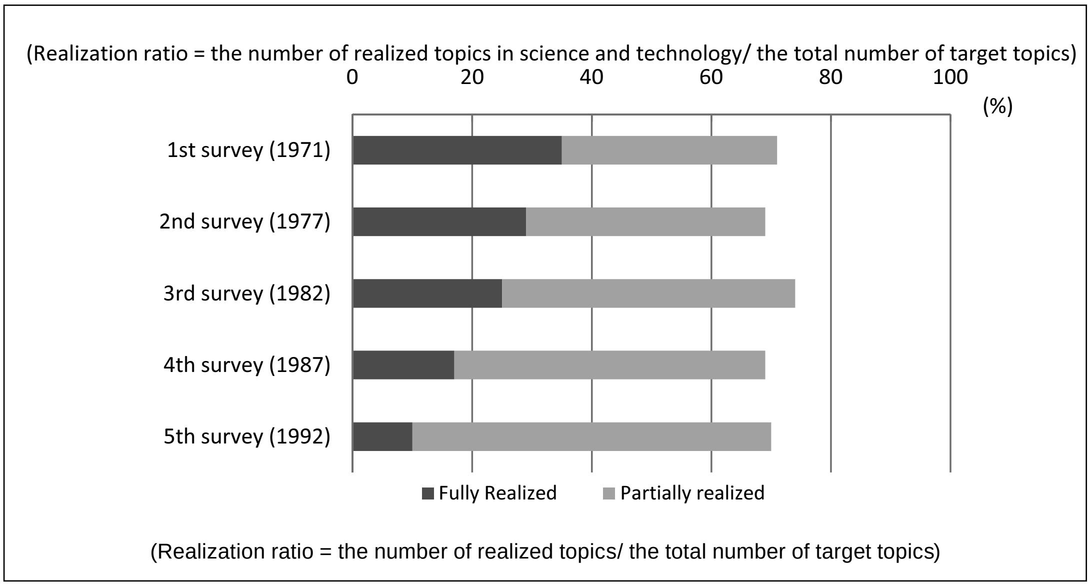

Figure 1 : Outcomes From First to Fifth Delphi Surveys: Realization Ratio

Prepared by the STFC

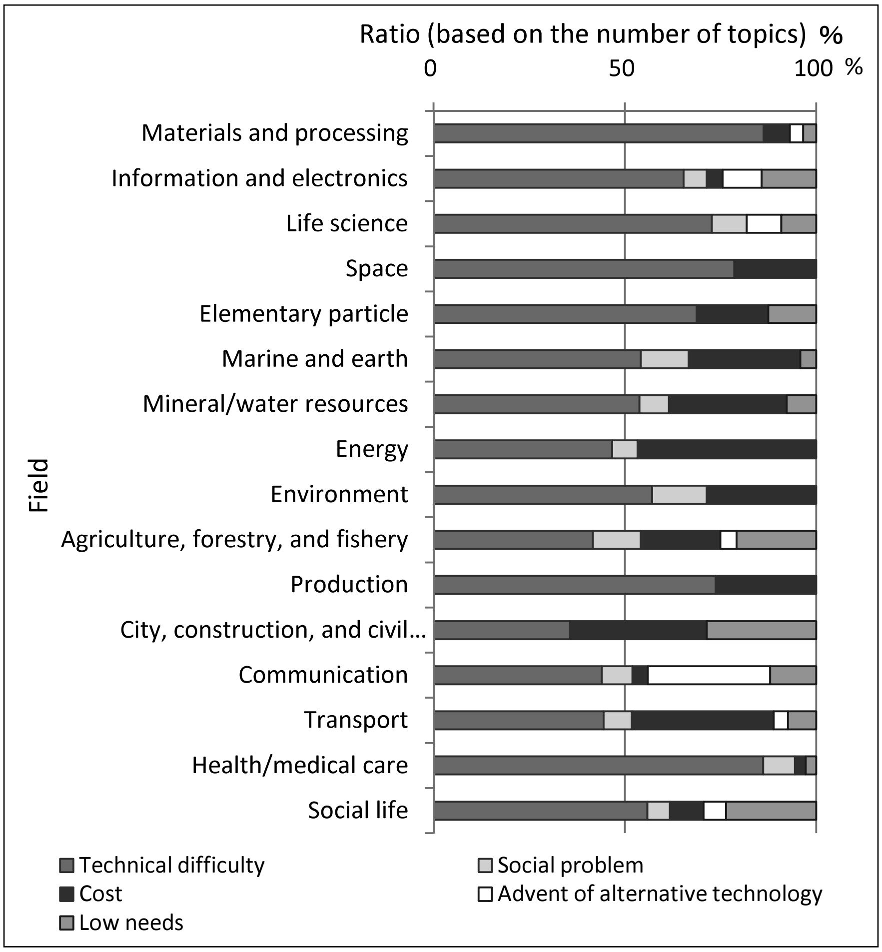

Figure 2 : Ratio of Reasons for No Realization of a Topic (5th survey)

Source: References[1]

Table 3 : Examples of Unrealized Topics in: (Those Predicted to Be Realized by 2009 in the 5th Delphi Survey)

Field	Topic	Predicted year of realization	Reason for no realization
Communication	Practical use of long-distance, large-capacity optical communication methods, ulitizing optical fibers and coherent optical communication technology (e.g. the optical hetrodyne method).	1999	Technical difficulty
Marine and Earth	Founding of an educational organization for earth-science research in the broad sense of the term, aiming at development of internationally active scientists and engineers as human resources that can contribute to global environmental protection, resource exploitation and protection.	2001	Social problem
Health/medical care	Development of an HIV vaccine	2003	Technical difficulty
Elementary particles	Practical use of a mass storage device that allows writing speeds in excess of 1GB per second.	2004	Technical difficulty
Health/medical care	Wide-spread use of a social system for secondary prevention of cancer (early detection) and enhanced knowledge among the general public make the average 5-year probability of survival of all types of cancers higher than 70% (current value: 50%).	2003	Technical difficulty, social problem, cost and other problems
Elementary particles	Practical use of pattern processing technology in the domain less than 10 nm, where synchrotron orbit radiation (SOR) is used as the light source of lithography.	2004	Cost and other problems
Communication	Establishment of an international ISDN network covering almost every country, enabling automatic connection to these countries from the ISDN network in Japan.	2004	Advent of alternative technology
Elementary particles	Practical use of an analytical instrument capable of ultra-low concentration analysis down to ppt [10^{-12}] level.	2004	Low needs
Materials and processes	Practical use of large-area, high conversion efficiency (>20%) amorphous solar cells.	2004	Technical difficulty
Life science	Practical use of therapeutic methods that prevent cancer metastasis.	2007	Technical difficulty
Production	Extensive use of room-temperature superconductive materials in industrial products.	2008	Technical difficulty
Energy	Practical use of disposal technology for solidified high-level nuclear waste.	2009	Social problem
Information and electronics	Advancement in verification technology leads to the rapid development of large-scale software and the elimination of errors.	2009	Technical difficulty

Prepared by the SFTC

4-1 Examples of Realized Topics

(1) Provision of Services through a Network

The provision of a variety of services through a network, such as information exchange, transport and accommodation reservations, and purchasing goods — as we see today provided by the Internet — were given in every survey. The term "Internet," as a matter of course, was not mentioned, but many of the desirable concepts were already introduced.

(2) Emergency Medical System

The topics related to the emergency medical system provided important themes from the early surveys, and, by and large, many of these have already been realized in Japan. Nevertheless, a topic directly related to this issue is still given in the ninth survey (".A flexible regional healthcare system capable of corrective modification, coping with regional differences, especially in terms of emergency medical care"), and it is predicted to be realized in 2021. A reemergence of similar themes as new topics of importance may well be expected as the established system gradually becomes inadequate in view of changing social situations.

(3) Cloning Technology of Somatic Cells

The term "cloned animal" became widely used by 1982. Actually, the first success in cloning from somatic cells, a cloned sheep named Dolly, was announced in February 1997, which somewhat preceded the experts' forecast. In the sixth survey (1997), the questionnaire was conducted just before the above announcement, and the experts predicted 2015 as the year when the "realization of cloning technology from a somatic cell of livestock" would occur.

The Delphi survey, because of its fundamental nature of consolidating a variety of opinions in a direction and giving survey results as a median estimate, has a weakness in that it may fail to reflect the prescient opinions of the minority, making it difficult to predict when and how a breakthrough technology will be realized. This is a typical case where this weakness was made visible.

4-2 Examples of Unrealized Topics

(1) Prevention of Carcinoma Metastasis

Owing to the advancement of diagnostic techniques, early detection and prompt therapy became feasible for certain types of cancer. However, although the mechanism that gives rise to malignant alteration of cancer is steadily becoming clear, a method to prevent carcinoma metastasis has not been developed and remains a topic of great concern even now. The time scope of the forecast set by each survey is normally from 15 to 20 years from the time of the survey, and this topic is one where the expected period of realization has been postponed every time the survey is conducted. The development of a drug that prevents carcinoma metastasis is also given in the ninth survey, and the prediction is that the technique will be established by 2023 and enter into general clinical application by 2032.

Table 4 : Topics Associated with Network Service

Survey No. (year)	Topics	Predicted year of realization
1st survey (1971)	Direct access to overseas databanks will become feasible, enabling direct data transaction with them.	1987
1st survey (1971)	Implementation of a world-wide network for transport/accomodation reservations (limited to large hotels in large cities and holiday resorts), and the establishment of a global real-time system.	1980
2nd survey (1977)	Establishment of an information guidance system using visual (bi-directional) communication enables the provision of a variety of information for enhanced convenience of daily life, and enables rich and varied life planning.	1987
3rd survey (1982)	Implementation of the international data communication network, covering almost every country, enables direct connection from Japan's domestic data communication network.	1994
4th survey (1987)	Leasing orders and a second-hand goods exchange system come into widespread use at the nation-wide level.	1994
5th survey (1992)	Widespread use of the communication system that enables search and browsing of static/dynamic images from an electronic library (textual information, books, static images, movies, television, documentary video library)	2005
5th survey (1992)	Practical use of an artificial reality computer network that enables geographically distant members of the general public to share a virtual space.	2005

Prepared by the SFTC

Table 5 : Examples of Topics Related to the Emergency Medical System

Survey No. (year)	Topics	Predicted year of realization
1st survey (1971)	Nation-wide completion of the network for emergency medical service, and establishment of an emergency conveyance system enabling rapid delivery of patients to the appropriate medical facility.	1986
2nd survey (1977)	Same as above.	1990
3rd survey (1982)	Establishment of a nation-wide emergency medical service system that provides appropriate medical service regardless of the geographical location of the patient: combination of well-placed local emergency centers under the control of the central medical center where all the data is diagnosed.	1997
5th survey (1992)	Widespread implementation of close communication between ambulances and hospitals (e.g. information from an image and knowledge database for emergency treatment).	2003

Prepared by the SFTC

Table 6 : Examples of Topics Related to Cloning Technology

Survey No. (year)	Topics	Predicted year of realization
1st survey (1971)	The development of an asexual reproduction technique for genetically homogeneous experimental animals, based on the tissue culture of somatic cells.	2000
3rd survey (1982)	Widespread use of reproduction techniques (including cloning) to produce experimental animals.	1999
5th survey (1992)	Development of techniques to grow an individual from an embryotic stem cell (a germinative cell at its very early stage).	2011

Prepared by the SFTC

(2) Large-area, High-efficiency Solar Cell

The solar cell, especially its conversion efficiency, area enlargement, and materials, has been one of the focuses since the first survey, and was expected to yield practical applications by the early 2000s. Area enlargement and efficiency improvement of the solar cell (“Large-area, High-efficiency Amorphous Solar Cells”) has been a topic in the material-related field, and has been given consecutively from the fourth (1987) to the eighth (2005) survey. This topic was assessed as “unrealized” at the time of the ninth survey. In the ninth survey, this topic is given under the title, “low-cost, large-area, thin-film solar cells with a conversion efficiency of 20% or higher” — note that the material is not specified. The forecast is that this technology will be established by 2019, and will enter into general use in society by 2027.

(3) Traffic Control System

A road traffic control system has also been given as a topic target since the first survey, and yet it has not been realized to this day. This is another example of topics that have experienced postponement from one survey to the next. However, the perspective from which the topic is viewed is gradually shifting: the main theme given in the seventh and preceding surveys (2001) was the determination of traffic volume and a system to control traffic flow, while in the eighth survey (2005) the focus shifted to the construction of a traffic demand management system that optimizes traffic flow in a comprehensive way, paying due attention to response from users. In the ninth survey, individual themes are given as the topics, such as the synchronization of traffic signals with engine control, working at home, and the enhanced utilization efficiency of expressways through the introduction of automatic driving.

4-3 Examples of Topics That Failed to Be Realized due to Reasons Other than Technical Difficulties

For the topics that have failed to be realized, the obstacles are classified into several categories (i.e. technical, social, cost and budgetary, the advent of alternative technology, and low needs) and shown in Figure 2. Table 10 shows the topics that failed to be realized due to reasons other than technical difficulties. Among these, those that failed to be realized because of “low needs” tended to have lower levels of importance than others at the time of the survey, indicating that they might have originally had limited importance.

Table 7 : Examples of Topics Related to the Prevention of Cancer Metastasis

Survey No. (year)	Topics	Predicted year of realization
2nd survey (1977)	Practical use of techniques that prevent cancer cell matastasis.	1993
3rd survey (1982)	Development of effective measures against cancer metastasis.	1999/2003*
4th survey (1987)	Same as above	2002/2005*
5th survey (1992)	Practical use of effective measures against cancer matastasis.	2007/2011*

* The survey gave two different years for realization because the same topics were was placed in two fields (medicine and life science).

Prepared by the SFTC

Table 8 : Examples of Topics Related to Large-area, Thin-film Solar Cells

Survey No. (year)	Topics	Predicted year of realization
1st survey (1971)	Solar cell materials with a conversion factor higher than 20% will be developed.	1984 (realized)
2nd survey (1977)	Solar cell materials with a high conversion factor (>20%) and low price level (1000th of the current level or even lower) will be developed.	1995
3rd survey (1982)	Amorphous silicon solar cells with a conversion factor higher than 8% will be put to practical use.	1990 (realized)
4th survey (1987)	Large-area amorphous silicon solar cells with a conversion factor higher than 20% will be put to practical use.	1998
5th survey (1992)	Same as above	2004

Prepared by the SFTC

Table 9 : Examples of Topics Related to a Traffic Control System

Survey No. (year)	Topics	Predicted year of realization
1st survey (1971)	A comprehensive traffic control system that enables uniform and smooth traffic flow by integrating such techniques as 2D control and route navigation will be established for major metropolitan areas (e.g. with populations larger than one million)	1983
2nd survey (1977)	Same as above	1996
3rd survey (1982)	A comprehensive traffic control system that enables uniform and smooth automotive-centric traffic flow by integrating such techniques as 2D control and route navigation will be widely used in medium to large urban areas (e.g. with populations larger than half a million).	1997 (Partially realized)
4th survey (1987)	Widespread use of a road traffic control system capable of keeping track of the traffic situation (the types and number of automobiles, flow density, etc.) and providing optimum control in urban areas.	1998
5th survey (1992)	Same as above	2003

Prepared by the SFTC

Table 10 : Examples of Unrealized Topics: Classified by the Reasons for No Realization

Reason	Topics	Survey No. (year)	Predicted year of realization
Social problem	Advancement of urban planning technology realizes a showcase of a large metropolitan area (with a population of around one million) where workplaces are well dispersed, resulting in an environment with a high-level of home-workplace mixing.	2nd survey (1977)	1998
	Around one percent of construction costs of public buildings in Japan will be used for additional cultural value: aesthetic appearance and harmony with the surrounding cityscape.	4th survey (1987)	2000
	Organ transplantation (kidney, heart, liver, etc.) will be performed more often, approaching the current level in Europe and the United States.	5th survey (1992)	2001
	Evaluation/utilization standard regarding the use of useful living objects created by biotechnology (genetic modification) in the open environment will be established. Living objects with useful characteristics for environmental purification will be put into practical use.	5th survey (1992)	2006
Cost	Advancement in oil substitution plant technology (development, improvement, and culture method) will lay the technical foundation for the widespread use of alternative energy (overseas products included)	4th survey (1987)	2011
	Advancement in deepsea mineral resource research (manganese, hydrothermal minerals, cobalt, and crust) will enable economic and selective practical mining of these resources.	5th survey (1992)	2006
	Power generation using the coal gasification hybrid cycle will be practically applicable.	5th survey (1992)	2005
	A variable wavelength, free-electorn laser will become widely used in medical applications.	5th survey (1992)	2007
Advent of alternative technology	Millimetric-wave wireless PCM (80-120GHz band) will become practically applicable.	2nd survey (1977)	1990
	Optical card memory with a capacity larger than 10 giga-bits will become widely used (i.e. for digital books).	4th survey (1987)	1997
	High-speed, wide-band switching equipment for multiplexing and time division switching of high-speed, wide band information will become practically applicable.	4th survey (1987)	1993
	An automobile navigation instrument that uses an optical fiber gyrocompass will become widely used.	5th survey (1992)	2004
Low needs	Major parts of software (including general-purpose systems) will be incorporated into hardware (i.e. they become firmware).	2nd survey (1977)	1991
	To make computers even easier to use, voice-input programming technology will become practically usable.	2nd survey (1977)	1996
	Improved rice growth technology will become widely used, enabling rice yields 1.5 times larger per unit area.	3rd survey (1982)	1998
	Electronic newspapers (through satelite/terrestial broadcasting) will become widely used (subscription will be protected by scrambling).	4th survey (1987)	2001

* Most of the topics that failed realization were taken up in more than one survey. The table shown above shows data from the latest surveys (1st to 5th).

Prepared by the SFTC

5 Areas of Science and Technology That Seem to Be Realized Earlier than Expected

A look at the assessment of the topics given in the past surveys (from the 1^{st} to 5^{th}), conducted twenty years after the predictions, reveals that twenty to thirty percent of the topics that were forecast to be realized at a time later than the assessment have already been evaluated as "realized" (including partial realization). These are examples of the topics that were realized earlier than expected.

Among the topics given in the fifth survey, an assessment made nearly twenty years later (toward the end of 2009) pointed out that thirteen topics were realized more than five years earlier than expected, and they are shown in Table 11. Nine of them are topics related to the life science or health care/ medicine fields, including such areas as the brain and neuroscience, regenerative medicine, and gene therapy.

The topics in the life science and health/medicine fields have been assigned a relatively long period for realization in every survey. Therefore, the same or similar topics have often been given in multiple surveys and the domains of topics often overlap. Noteworthy here, however, is the fact that nearly half of the topics that were forecast to not be realized by the time of the assessment have actually been realized (or, partially realized).

Figure 3 summarizes the realization status of the topics that were forecast in the fifth survey to take a long period of time. In the life science field, there were 46 topics that were forecast to be realized later than 2010, accounting for nearly half of all topics in the field. Actually, 29 of these topics were assessed as realized (or partially realized) as of the end of 2009. In contrast, in the energy and space fields, where many of the topics are also expected to take a long period of time before realization, only one or two topics have come to fruition earlier than predicted .

Life science and related areas are considered to have a wide global scope for breakthroughs in the days ahead, and one of the weaknesses of the Delphi survey lies in its general unsuitability to predict discontinuous advancements. Life science and health/medicine are considered to be areas with clear, long-term objectives that are less prone to modification over time. These indicate the risk of such simple, stereotyped thinking that, "it must require a long period of time before realization."

6 Conclusion

In Delphi surveys, incompatible technologies are sometimes given as future options, and even a topic that seems to challenge others may be given to probe future direction. The fact that nearly seventy percent of the topics including those seemingly challenging cases, have been realized in one way or another reveals the significance of the uninterrupted implementation of Delphi surveys and the reliability of a certain amount of the results, as well as the surveys' substantial value as an intellectual asset. It should be noted, however, that the major results from a Delphi survey may have ignored minority opinions, and there may remain important technologies that have escaped the attention of the survey.

A glimpse into the views and insights of the experts in the past also encourages us to ask ourselves if we have the same level of insight as they did. Perhaps we have to consider by ourselves if we have a power of prediction now that will be highly appreciated by experts in the future.

Table 11 : Examples of Topics That Were Assessed to Have Been Realized more than Five Years Earlier than Expected (The forecasts given in the 5th survey [1992] were assessed at the time of the 9th survey [toward the end of 2009])

Field	Topic	Predicted year of realization	Realization status at the end of 2009
Life Science	An interface directly connecting the brain and a computer will be developed.	2020	Partially realized
Life Science	Technology for artificial cell synthesis, for replacing some of the functions of natural cells, will be developed.	2019	Partially realized
Life Science	The link between the thought process and the neuron activities inside the brain will be clarified.	2018	Partially realized
Life Science	Artificial intelligence technology that mimicks the thought process in the brain will be developed.	2017	Partially realized
Life Science	The neurobiological foundation underlying human emotion will be clarified.	2017	Partially realized
Health/Medical Care	Techniques for artificial preparation (excluding fetus cells) and transplantation of a cell that can grow and provide an organ function will be developed (e.g., as a therapeutic method for Alzheimer disease).	2020	Partially realized
Health/Medical Care	Electric circuitry directly connectable to neuro/brain cells will be developed and applied in an artificial eyesight system.	2019	Partially realized
Health/Medical Care	The mechanism of individual aging will be clarified, and the knowledge will be applied to anti-aging therapy.	2018	Partially realized
Health/Medical Care	Gene therapy will become practically applicable to many gene-defect diseases.	2016	Partially realized
Space	Space tourism around the earth on board a spaceship will become available.	2016	Partially realized
Marine and Earth	Combined efforts of humans — technological advancement of natural energy ulitization, the reduction of man-made heat generation, and the suppression of heat accumulation in the atomosphare — will facilitate a balance in the heat budget of the earth.	2016	Partially realized
Mineral/Water Resources	Technology for artifical precipitation (in case of drought) will become practically applicable.	2015	Partially realized
Environment	The presence or absence of persistent effects of environmental pollution on humans (i.e., inherited from one generation to the next) will be clarified.	2015	Partially realized

Prepared by the SFTC

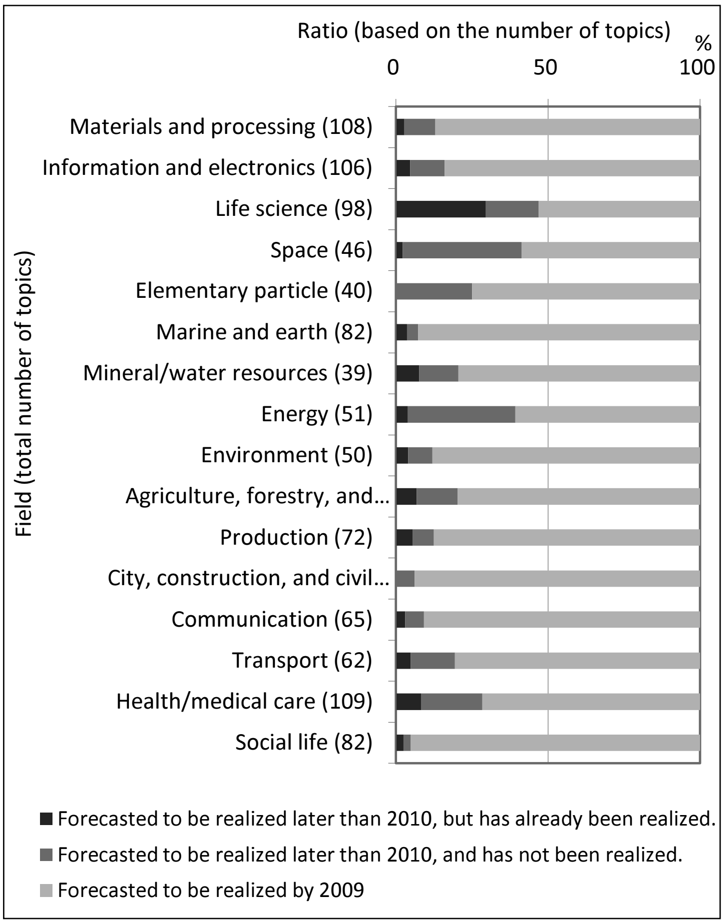

Figure 3 : Realization Status of Topics in Science and Technology That Were Forecasted to Take a Long Period of Time before Fruition

(The forecasts given in the 5th survey [1992] were assessed at the time of the 9th survey [toward the end of 2009])

Prepared by the SFTC

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The 9th Delphi Survey:
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Future Scenarios Opened up by Science and Technology:
http://www.nistep.go.jp/achiev/ftx/jpn/rep141j/idx141j.html
Capability of Local Regions for the Green Innovation:
http://www.nistep.go.jp/achiev/ftx/jpn/rep142j/idx142j.html
* For the realization status assessment of past Delphi surveys, see "The 9th Delphi Survey."

[2] Past Delphi surveys:
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Profile

Yoshiko YOKOO
General Unit
Science & Technology Foresight Center
Yoshiko Yokoo was engaged at the NISTEP in the survey on resources and human resources in science and technology. She is now in charge of the survey on science and technology foresight.

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6

Main Points of White Paper on Science and Technology 2010

Yuko Ito
Division of Research and Coordination, Science and Technology Policy Bureau

1 Introduction

On June 15, 2010, the "White Paper on Science and Technology 2010 (annual report on the promotion of science and technology in fiscal 2009)"[1] was decided at a Cabinet meeting and was reported to the Diet.

The White Paper on Science and Technology, which is stipulated in Article 8 of the Science and Technology Basic Law (Law No. 130 of 1995), is a report on measures implemented by the government concerning the promotion of science and technology. On the other hand, the White Paper on Education, Culture, Sports, Science and Technology, which is not a legally-required document, offers a broad introduction of measures implemented by the Ministry of Education, Culture, Sports, Science and Technology (MEXT). They are both prepared by the MEXT but their orientation is different.

As Table 1 shows, Part 1 of the science and technology white paper focuses on a different theme every year. Initially, the white paper consisted of three parts, but starting with the FY2008 edition, it has come to incorporate in Part 1 the "Current Status of Science and Technology in Japan and Other Nations," which had previously formed Part 2.

Part 2 of recent science and technology white papers, "Measures Implemented to Promote Science and Technology" (which formed Part 3 of previous white papers), carries reports prepared by ministries and agencies on measures adopted by them for the promotion of science and technology in the previous year.

Part 1 of the FY2010 white paper focuses on "A new frontier to be extended by value-creating human resources ~ How science and technology should be for Japan to make a new start."

"Value-creating human resources" is a coined phrase meaning "human recourses essential for the creation of new values." They include "not only researchers and engineers but also persons involved in the management of universities, research institutes, private corporations and administrative organizations, intellectual property-related human resources, persons engaged in industry-academic-government collaboration, and science and mathematics teachers fostering next-generation human resources." Japan is faced with a host of challenges, including global threats, such as global environmental issues, and socio-economic issues, such as the declining birthrate and the growing proportion of elderly people. Under such severe circumstances, in order to continue to create innovations and generate new values in Japan, it is necessary for all human resources working actively in various fields to further enhance their respective creativity and productivity. It is also important to develop a society where such value-creating human resources can perform their skills.

In light of these circumstances, Part 1 of this year's white paper takes up the issues of strengthening science/technology and basic scientific capability conducive to the solution of problems in Chapter 1, developing human resources, improving the research environment, and creating opportunities to generate innovation in Chapter 2, and considering the relationship between society/people and science/technology in Chapter 3. Throughout the chapters, the white paper explains that there are various problems with regard to human resources in Japan and that these problems need to be solved.

(Incidentally, in this year's white paper, "*kagakugijutsu*," a generic term used to refer to "*kagaku* (science)" and "*gijutsu* (technology) is written as "*kagaku・gijutsu*," except for referring to law names, for the first time in line with the notation adopted in other government documents, such as the "New Growth Strategy (Basic Policy) (Cabinet decision in December 2009)."

The following are the main points, chapter by chapter, of Part 1 of this year's white paper on science and technology.

2 Main Points of Part 1

2-1 Points of "Chapter 1: Science and Technology Carving out a Future and Solving Challenges"

Chapter 1 first describes world situations surrounding Japan as the background of science and technology policy.

Table 1 : Structure and Titles of Science and Technology White Papers
*Figures in the brackets are the number of pages

Issue date	Title of Part 1	Title of Part 2	Title of Part 3
1996	Aiming for Front Runner in Research Activities	The Current Status of Science and Technology in Japan and Other Nations	Measures Adopted for Promotion of Science and Technology
1997	Aiming for Creating an Open Research Society	The Current Status of Science and Technology in Japan and Other Nations	Measures Adopted for Promotion of Science and Technology
1998	In the Era of Reform	The Current Status of Science and Technology in Japan and Other Nations	Measures Adopted for Promotion of Science and Technology
1999	New Developments in Science and Technology Policy: Responding to National and Societal Needs	The Current Status of Science and Technology in Japan and Other Nations	Measures Adopted for Promotion of Science and Technology
2000	Towards the 21st Century	State of Science and Technology Activities in Japan and Overseas	Policies Adopted to Promote Science and Technology
2001	Creativity of Japan's Science and Technology	The Current Status of Science and Technology in Japan and Other Nations	Measures Adopted for Promotion of Science and Technology
2002	Using Knowledge to Create Society and Economy for a New Era	The Current Status of Science and Technology in Japan and Other Nations	Measures Adopted for Promotion of Science and Technology
2003	Human Resources in Science and Technology Required of Japan in the Future	The Current Status of Science and Technology in Japan and Other Nations	Measures Adopted for Promotion of Science and Technology
2004	The Future of Science and Technology and Society	The Current Status of Science and Technology in Japan and Other Nations	Measures Adopted for Promotion of Science and Technology
2005	Japan's Scientific and Technological Capabilities	The Current Status of Science and Technology in Japan and Other Nations	Measures Adopted for Promotion of Science and Technology
2006	Challenge for Building a Future Society: the Role of Science and Technology in an Aging Society with Fewer Children	The Current Status of Science and Technology in Japan and Other Nations	Measures Adopted for Promotion of Science and Technology
2007	Results of Promotion of Science and Technology – Creation, Utilization and Succession of Knowledge –	The Current Status of Science and Technology in Japan and Other Nations	Measures Adopted for Promotion of Science and Technology
2008	The State of Science and Technology in Transcending the Storm of Fierce International Competition (97)	Measures Implemented to Promote Science and Technology (126)	
2009	Towards Japan's Own Innovative Science and Technology across the Threshold of Global Transition (85)	Measures Implemented to Promote Science and Technology (140)	
2010	A new frontier to be extended by value-creating human resources ~ How science and technology should be for Japan to make a new start (99)	Measures Implemented to Promote Science and Technology (124)	

Source: Homepage of the MEXT[2]

Situations surrounding Japan, such as global environmental issues, are severe. In order to respond to the demands from society and the people, it is important to promote basic research, which is the source of knowledge, and research and development conducive to the solution of problems (technologies to cope with global warming, S&T conducive to people's health, and S&T conducive to social safety) and create innovation. It is necessary to clarify our intention to pioneer the future of Japan and humanity.

(1) Science and technology contributing to creation of a low-carbon society

(State of research and development aimed at solving global warming issues)

There are active movements around the world to cope with global warming and realize a low-carbon society. According to the UN Environment Program (UNEP), the global market for environment-related business, which stood at about €1.0 trillion (about ￥150 trillion) in 2005, is expected to more than double to about €2.2 trillion (about ￥300 trillion) by 2020.

Efforts for developing technologies to cope with global warming have intensified around the world. For instance, the number of research papers on solar cell and fuel cell power generation systems has increased both in Japan and other countries (Figure 1). The number of research papers on the dye-sensitized solar cell, which is drawing attention as a next-generation technology, has also increased drastically, suggesting active R&D activities in this area.

The following are examples of R&D of global warming countermeasure technologies.

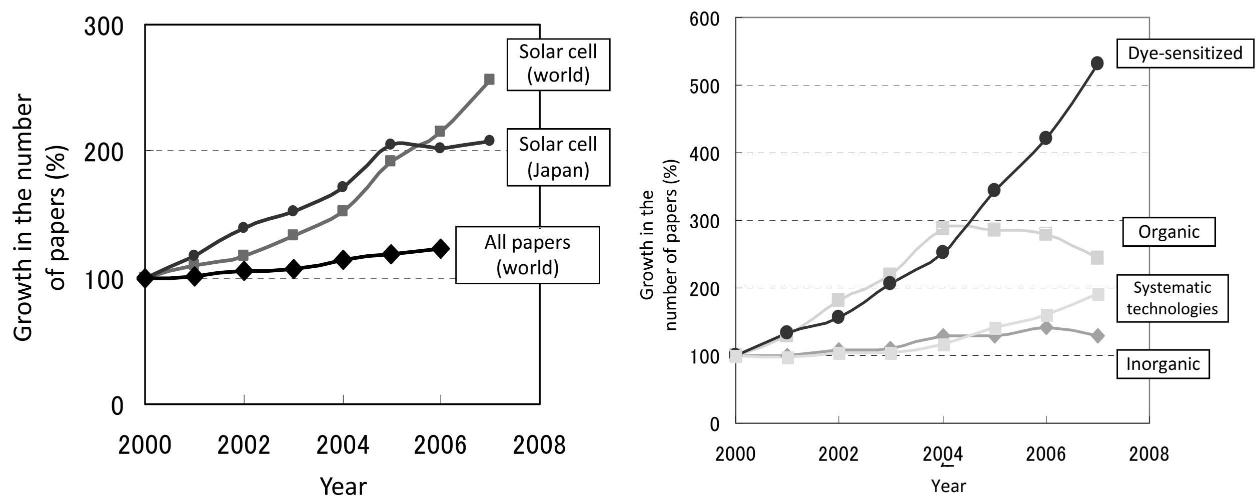
○ Technologies to reduce greenhouse gas emissions (R&D of next-generation solar cells, Biomass energy technology, R&D of electric storage technology, R&D of fuel cell power generation system, Smart grid technology, Carbon dioxide capture and storage technology)

○ Adaptive technology for global warming and environment prediction/observation technology

○ International joint research to facilitate solving global warming issues

(Integration of knowledge to realize a low-carbon society)

In order to promote research and development of global warming countermeasure technology, it is hoped that as many excellent researchers, basic scientists in particular, as possible will take interest in global warming issues and realizing a low-carbon society and get actively involved to solve the issues. It is important to share the common goal of realizing a low-carbon society, to promote comprehensive efforts involving researchers in diverse fields, including those in natural science as well as those in art and social sciences, and to facilitate smooth collaboration and networking of researchers and research institutes in various fields.



The left figure shows the increase in the number of papers in Japan and the world.
The right figure shows the increase in the number in the world for different types of cells.

Figure 1 : Increase in the number of papers in the world and in Japan in relation to solar cells and fuel cell power systems

Source: Innovation Policy Research Center, University of Tokyo

(2) Science and technology contributing to safe and sophisticated human life

In order for the people to enjoy healthy and high-quality life, it is necessary to promote R&D and innovation conducive to the creation of innovative medicines and healthcare technology and propel further growth of Japan by positioning industries based on science and technology related to medical-, nursing- and health-care as Japan's leading industries.

Research and development in these fields plays an important role in building a foundation for safe and high-quality national life. However, since it takes much time and effort to develop a viable industry and since it is not easy to produce short-term results, it is necessary for the government to actively promote such efforts.

(Science and technology conducive to people's health)

Challenging R&D efforts are being made in life science and many other fields ranging from basic research, such as investigation of vital functions and the cause and condition of diseases, to research and development of new medicines, medical equipment and medical-treatment and nursing-care technologies.

The following are R&D examples.

○ Research to deepen understanding of living bodies and develop future medical treatment methods
  - Shedding light on the mechanism of the living body's pathogen recognition (innate immunity)
  - Research on diseases and development of medicines and medical technology by using genetically-modified primates

○ Research on innovative medical technology conducive to the treatment of cardiac disease, cancer and dementia
  - R&D to realize regenerative medicine using iPS cells
  - Innovative tissue-engineered regeneration medicine
  - New drug treatment of cancer ~ Development of peptide-vaccine treatment
  - Research to shed light on the cause of impaired cognitive function

○ R&D leading to new medical equipment and service support
  - R&D of radiotherapy equipment that automatically tracks and treats malignant tumors
  - Life-supporting service robot

○ Efforts for health science through interdisciplinary collaboration, including art and social sciences.
  - Research and education centers for interdisciplinary study on aging society
  - "Silver New Deal," a policy recommendation in business-academia collaboration
  - Promotion of good health in collaboration with local communities

(Science and technology conducive to social safety and security)

In order to build a society where people can live in peace and security, it is necessary to have measures in place to prevent the occurrence of incidents that may cause immense influence on people's life, or to minimize the influence of such incidents.

The following are R&D examples.

○ Science and technology to prevent/reduce natural disasters

○ Science and technology ensure stable supply of foods ~ cultivation technology ~

○ Science and technology to detect dangers, such as terrorism

○ Promoting countermeasures against emerging/reemerging infectious diseases in collaboration with other countries

○ Science and technology to resolve water issues in the world

(3) Enhancement of basic science capability

(Importance of basic research)

Basic research creates human wisdom and is the source of knowledge. It also creates knowledge, which is the source of innovation. The 3rd Science and Technology Basic Plan states that research based on the free ideas of researchers promotes a variety of research activities from the very early stages in the pursuit of universal knowledge from a long-term perspective. The Basic Plan also states that such research has been supported by grants-in-aid for basic research and scientific research.

However, Figure 2 shows that "the diversity of basic research in Japan as a whole" has decreased from what it was in 2001. It also points out that a decrease in research funds from the basic research subsidy foundational budgets may impede unique and creative research by young researchers who have the potential to produce world-leading research results.

(Toward strengthening Japan's basic scientific capability)

The Basic Scientific Capability Enhancement Committee of the MEXT conducted intensive discussions on strengthening Japan's basic scientific capability and came up with a "Proposal toward Strengthening Basic Scientific Capability" in August 2009. It calls for integrated promotion of the S&T system, including investment in basic research, improvement of research infrastructure, and development of human resources with the aim of raising the education and research capability of Japanese universities and research institutions and "leading the world with science and technology."

(4) Current situation in Japan viewed in the papers

We need to be careful when we analyze research paper-related indicators, such as the number of research papers issued and the number of times research papers are cited, as they have their good points and bad points as well as their limits. Still, they show one aspect of the level of Japanese science and technology and therefore are basic information to understand the current state of the Japanese S&T system.

The number of top 10% research papers in all disciplines in Japan (the number of papers in the top 10% group in each discipline in terms of times the papers are cited) increased from 3,470 in 1988 to 5,283 in 2008. On the other hand, while the number of top 10% papers in China has drastically increased its share in the world, the shares of Japanese and U.S. top 10% papers have decreased (Figure 3).

2-2 Main Points of "Chapter 2: S&T Systems that Mobilize People and Connect Knowledge"

Based on the progress in international science and technology and Japan's position that were described in Chapter 1, Chapter 2 analyzes the current state of human resources in Japan, the research environment, and conditions of innovation creation, and describes the kinds of human resources and environment required.

In order to create scientific and technological innovation contributing to the enhancement of basic scientific capability and the solution of issues, it is essential to develop and secure not only researchers and engineers but also "value-creating human resources" playing important roles in science and technology activities.

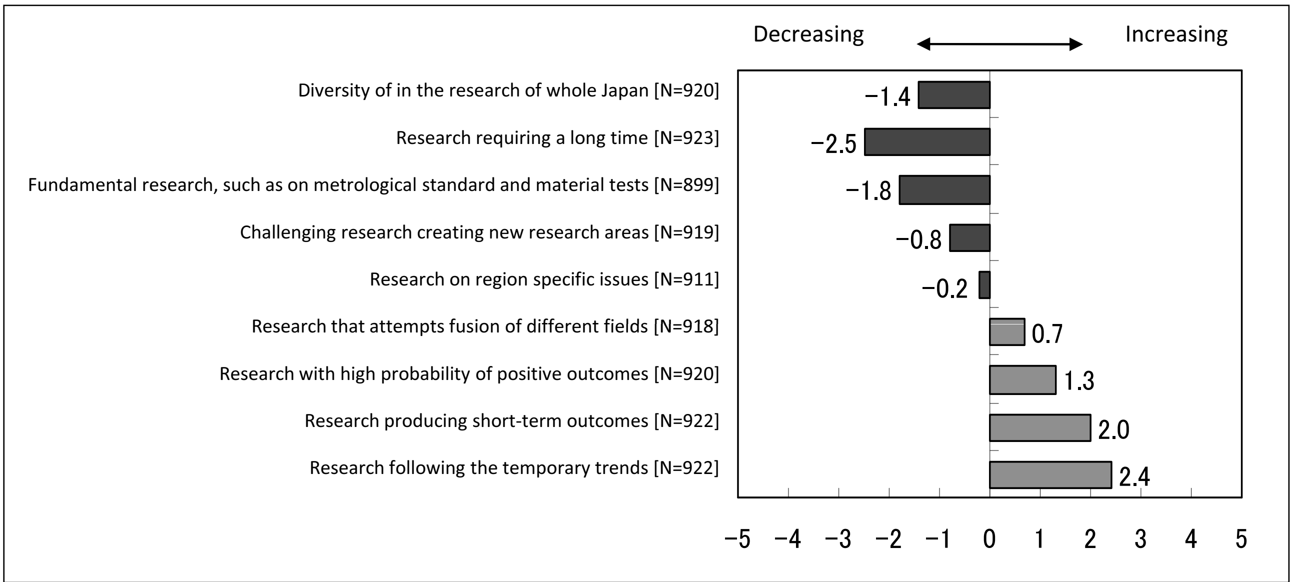


Figure 2 : Diversity in the basic research (Comparison to around 2001)

Source: "Analytical Report for 2009 Expert Survey on Japanese S&T System and S&T Activities by Fields," National Institute of Science and Technology Policy (NISTEP)

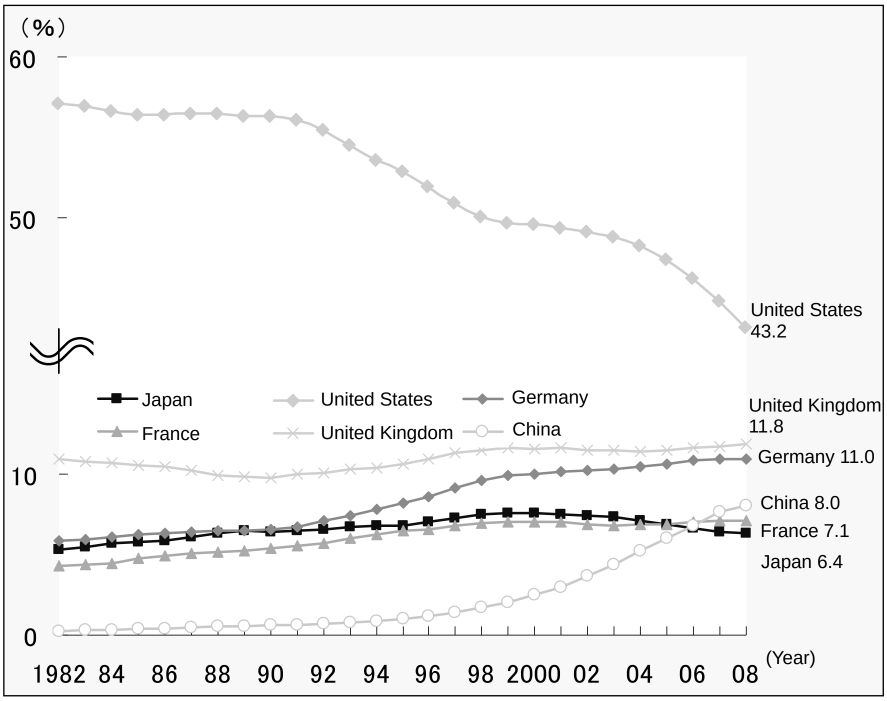


Figure 3 : Trends in the share of top 10% papers in selected countries

Source: Prepared by the NISTEP

(1) Developing value-creating human resources

① Promotion of human resources development and their performance

(Present state of career path of doctorate degree holders and their problems)

There has been growing need for human resources capable of creating new values required by the society. It is hoped that doctoral degree holders can do well in such fields.

The number of persons holding a doctoral degree in natural science per million population in Japan is much smaller than in Germany and the United Kingdom and even smaller than in South Korea (Figure 4).

The number of enrollments in doctorate courses in natural science in Japan, which had been increasing since 1991 on increased focus on postgraduate courses, decreased to 11,348 in 2009 after hitting a peak of 13,190 in 2003. The advancement rate from master's course to doctorate course in natural science has been on a declining trend in recent years, especially in the physical sciences and agricultural sciences fields (Figure 5).

A look at the trends in the number of doctoral graduates in natural science, in the number of newly recruited university faculties, and in the age structure of university faculties reveals that the number of doctoral graduates has exceeded the number of newly recruited university faculties since 1997 and that the ratio of young university faculties aged 37 or younger has been decreasing, while the number of postdoctoral fellows has been on an increasing trend.[3] This suggests that it has become difficult to follow an academic career path "to university faculties after completing doctorate courses and postdoctorate research."

(Diversification of career path of doctorate degree holders)

Private corporations, along with universities, are major employers. About 16% of persons who have completed doctoral courses in natural science are employed by private corporations.[4] Private Japanese corporations appear to be reluctant to recruit persons who have completed a doctorate course, with the percentage of corporations recruiting doctoral graduates "every year without fail" or "almost every year" standing at about 10%.[5] And, only 4% of researchers at private corporations are doctorate degree holders.

Doctorate degree holders can effectively use their talents as intermediaries between science/technology and the society (such as human resources related to intellectual property, coordinators for industry-academia-government collaboration, and science/technology communicators), managers of advanced science/technology (such as technology managers, program officers, and research administrators

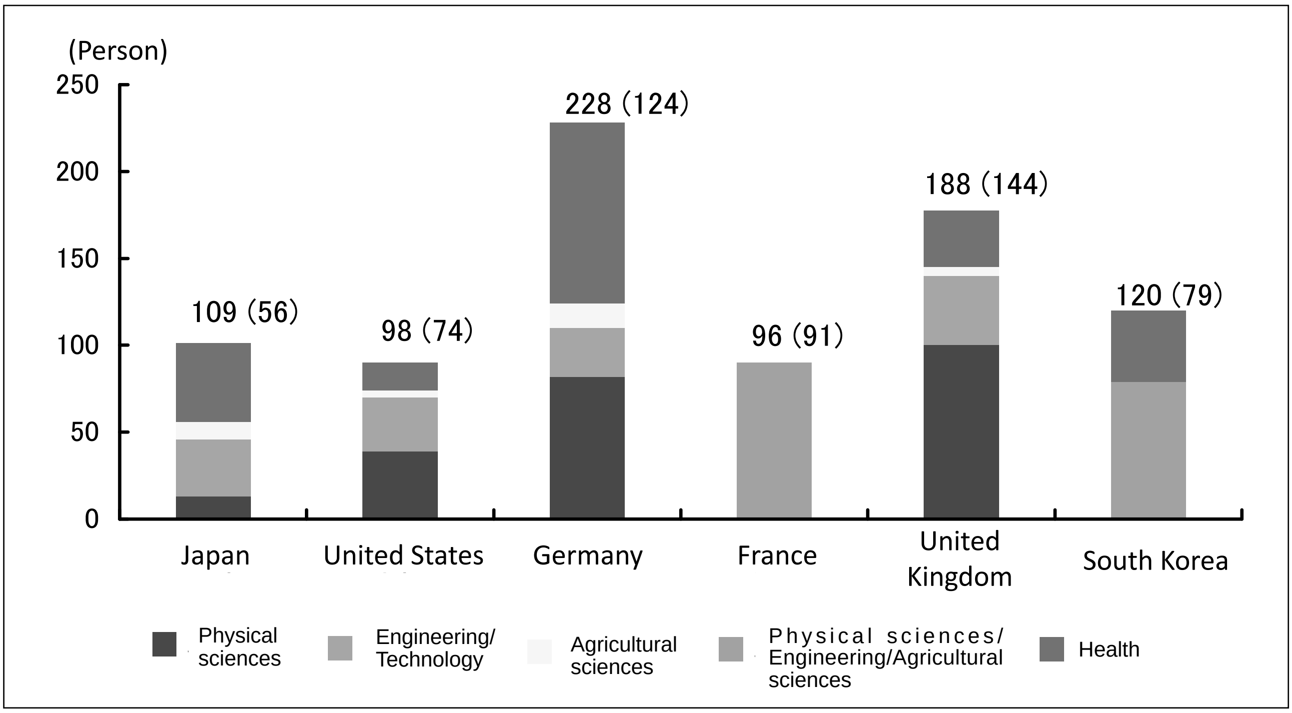


Figure 4 : Number of doctoral degree holders in natural sciences per million population in selected countries (2005)

Source: The numbers of doctoral degree holders are based on "International Comparison of Education Indexes (2008 and 2009)," MEXT. The populations are based on "Main Science and Technology Indicators Vol. 2009/2," OECD.

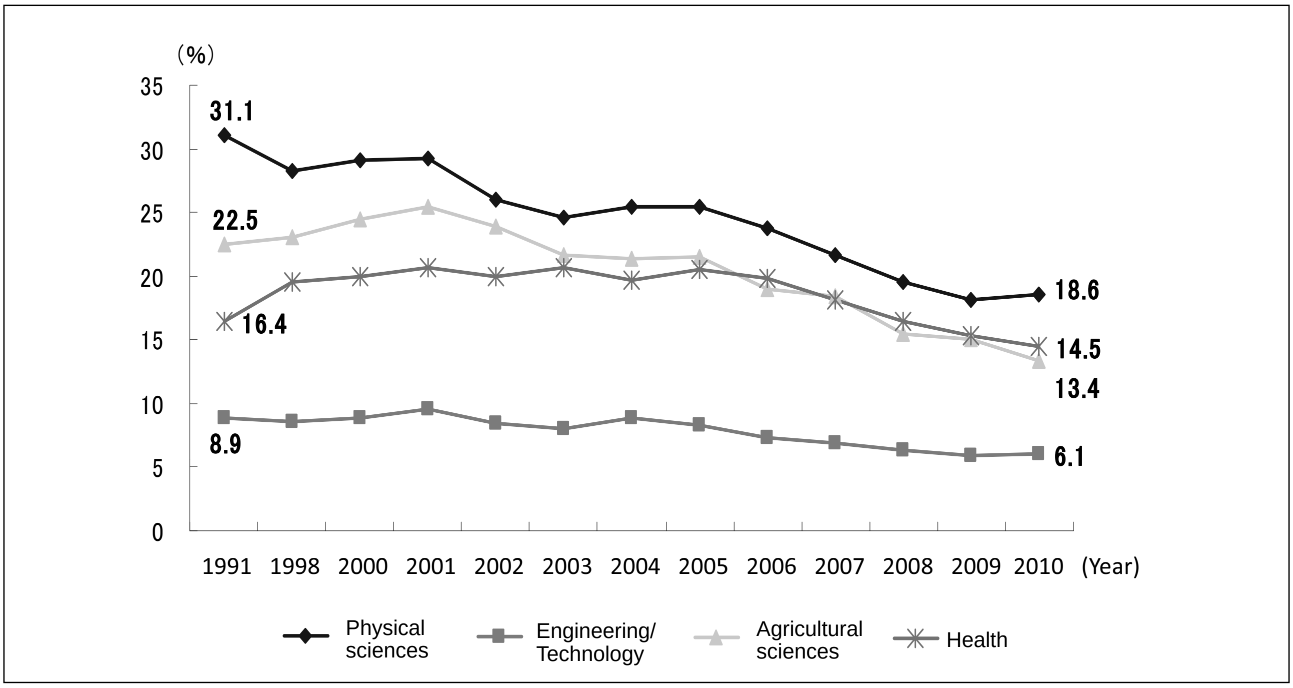


Figure 5 : Trends in the ratio of students in master's course advancing to doctoral course (Natural Sciences)

Source: "School Basic Survey," MEXT

providing research support from the aspect of application and management of competitive fund), science teachers at junior/senior high school, and administrative officers, such as national public servants. Society, for its part, is required to positively develop an environment so that doctoral degree holders can exert their talents in various fields.

② Development of creative research environment (Current state of research time)

A look at changes in university faculties' full-time equivalent factors (Figure 6) shows that the average hours for research activity in all fields decreased in 6 years from fiscal 2001 to fiscal 2007. Although total working hours both in the areas of natural science and human and social sciences did not change much from fiscal 2001 to fiscal 2007, hours spent for research activity decreased, while hours for education activity and hours for social service activity increased. By sector, researchers in science had the longest hours for research activity and those in engineering had the longest hours for education activity.

In order to help researchers produce better study results by effectively and efficiently utilizing their limited hours for research activity, it is essential to improve the research environment, including the improvement of R&D support and operation functions.

(R&D expenditures)

An international comparison of trends in R&D expenditures in major countries shows that, while R&D expenditures in China and the United States have increased, Japan's R&D expenditures decreased in FY2008 for the first time in 9 years as private corporations, which account for about 80% of Japan's R&D expenditures, slashed their spending on research (Figure 7). The ratio of R&D expenditures to Japan's gross domestic product is 3.8% and the ratio of government research fund to GDP is 0.68%.

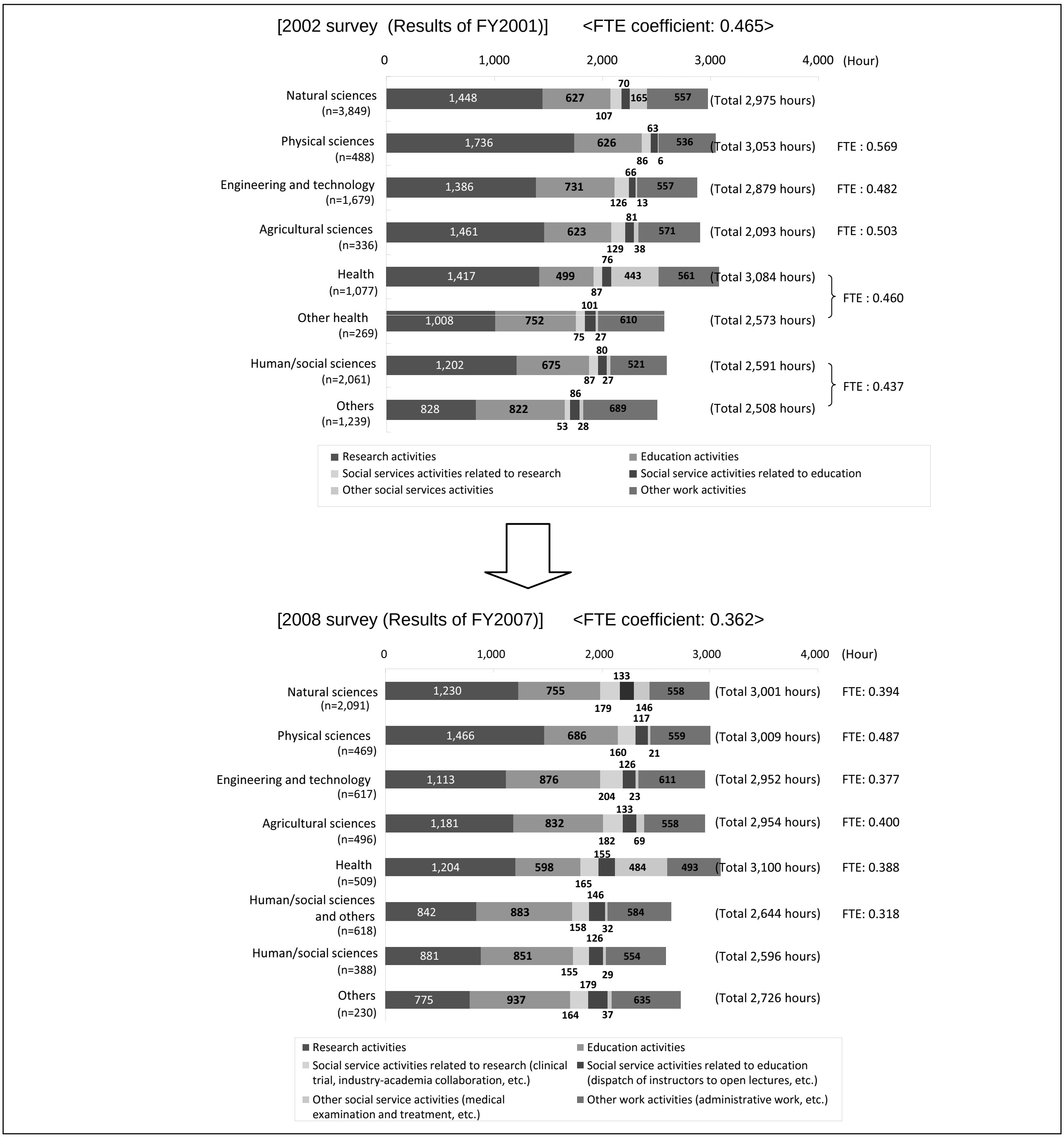


Figure 6 : Changes in total working hours and activities of university faculty (from FY2001 to FY2007)

Source: "Survey on Full-Time Equivalent data for research staff members in higher education organization. (September 2009)," MEXT

(2) Creation of opportunities to connect knowledge with innovation

① Current state of Innovation activities

(Innovation activities in companies)

Although the number of patent applications by Japanese has been on the decrease since 2005, Japan still leads the world (2008) in terms of the number of patent applications by country of origin. Japan is also number one worldwide in terms of the number of patent registrations.[6]

High-tech products (aerospace, electronics, office machinery and computers, pharmaceuticals, medical/precision/optical instruments) are high value-added products, as they utilize advanced science and technology in their mechanisms and production process and they create innovation by influencing social life. A look at the trends in major countries' share in exports of high-tech products reveals that China has increased its share drastically and increased its presence in the world market, while Britain, the United States and Japan saw their shares decline sharply (Figure 8).

Innovation can be divided into two categories: "product innovation, which is launching new products or new services into the market" and "process innovation, which is introducing new processes related to production and distribution of products and services, or improving existing processes." In a survey on the state of innovation activities within Japanese private-sector corporations (Figure 9), nearly half of the respondents said that they realized product innovation or process innovation during the three years from FY2006 to FY2008. Many of the 2,201 corporations that responded that they had realized innovation cited "deficiency in know-how related to technology" and "shortage of competent workers" as factors inhibiting innovation. In corporate innovation activities, it is important to expand human resources having advanced knowledge, information and technology.

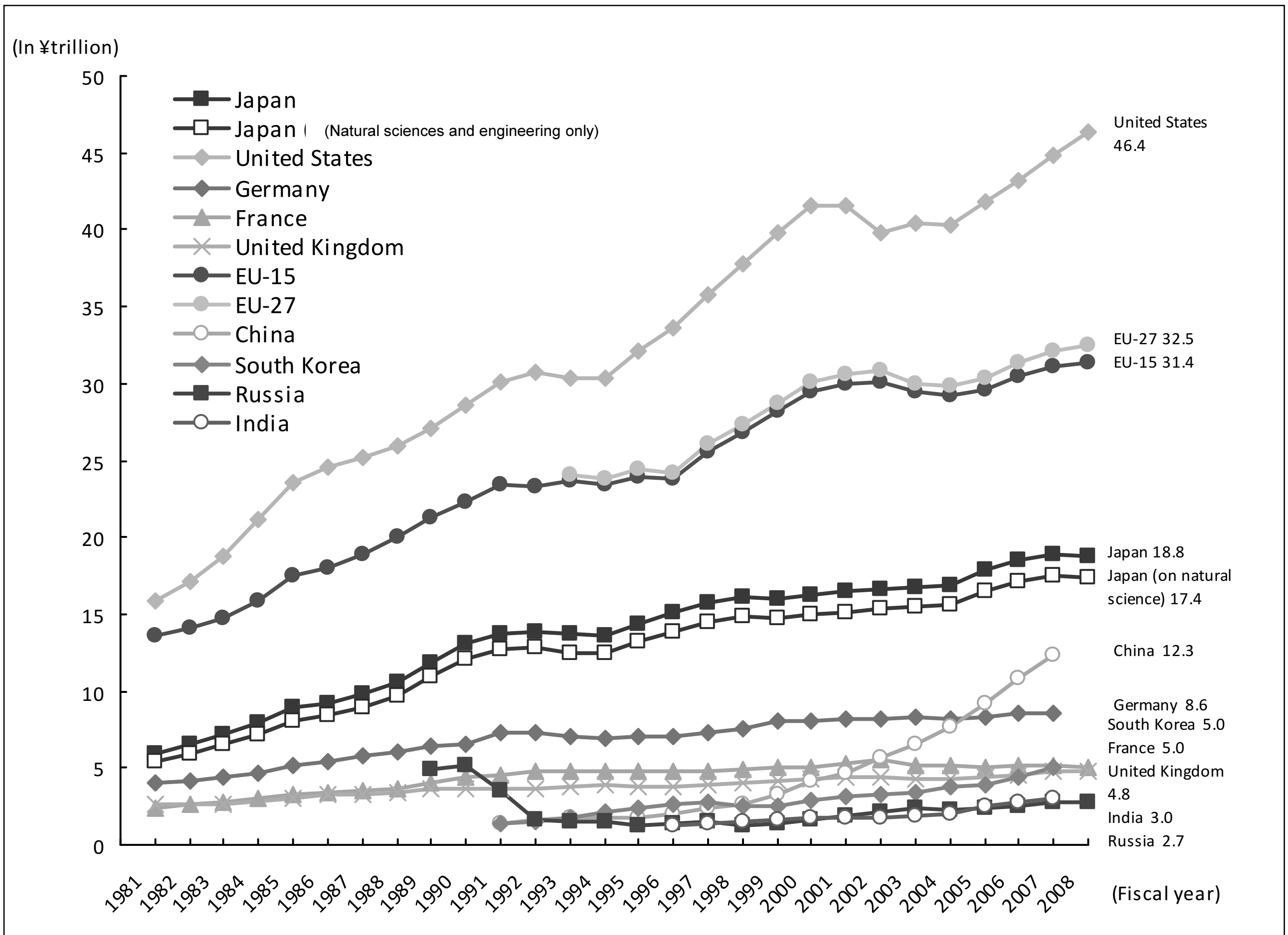


Figure 7 : Trends in R&D expenditures in selected countries/regions (on Purchasing Power Parity basis)

Source: Japan: "Survey Report on Science and Technology Research", Statistics Bureau of the Ministry of Internal Affairs and Communications; EU: Eurostat database; India: (Research fund) UNESCO Institute for Statistics R&D database and "purchasing power parity) The World Bank "World Development Indicators CD-ROM-2009; Other countries; OECD "Main Science and Technology Indicators Vol. 2009/2"; OECD purchasing power parity: OECD "Main Science and Technology Indicators Vol. 2009/2"

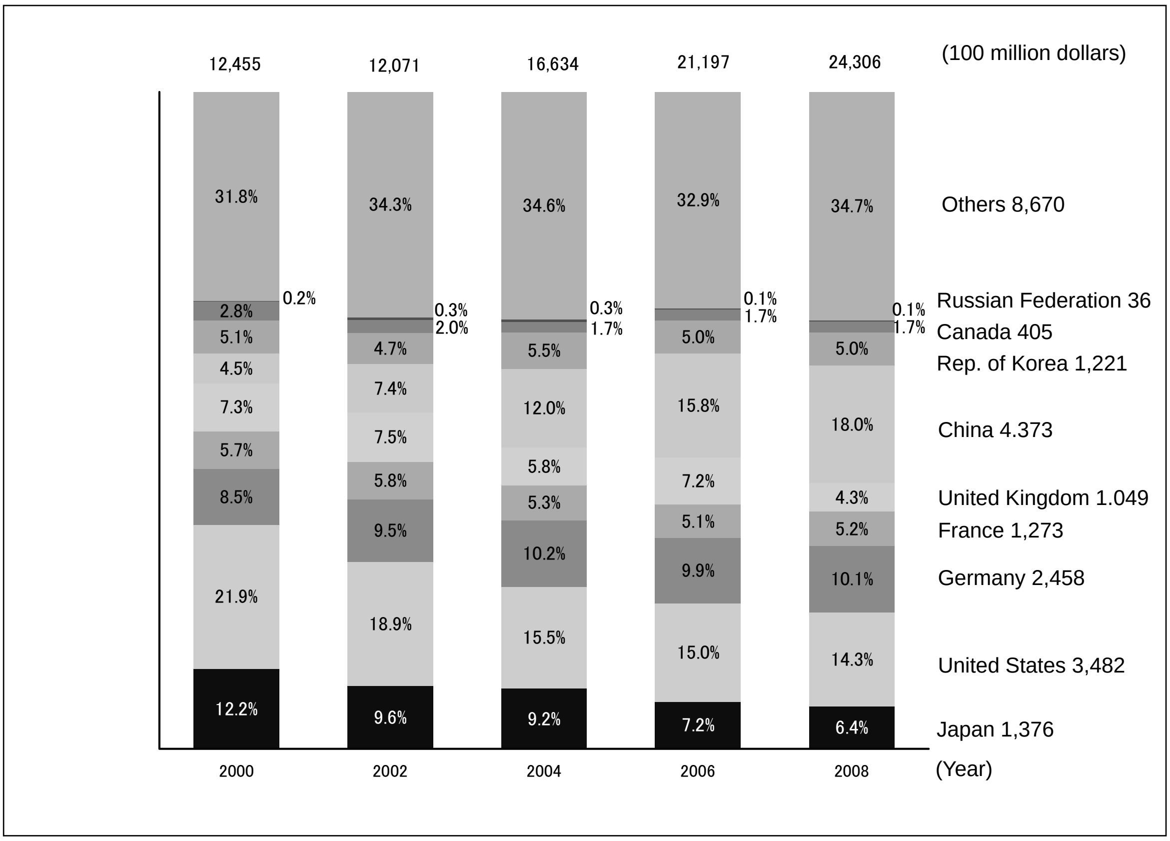


Figure 8 : Export market share for high-tech products in selected countries
Source: OECD "Main Science and Technology Indicators Vol. 2009/2"

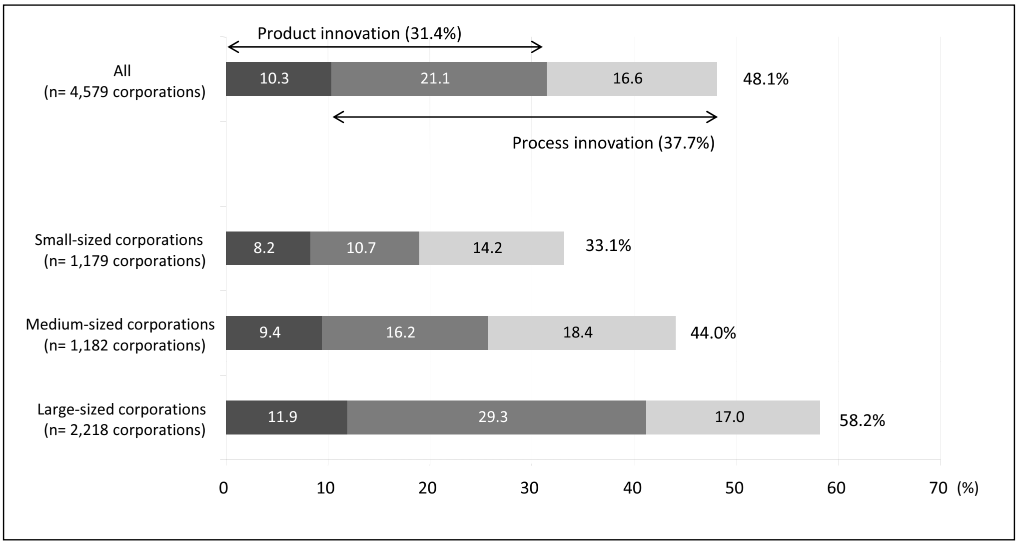


Figure 9 : Percentage of companies that realized innovations
Source: "Report on Japanese National Innovation Survey 2009," NISTEP

(Industry-academia collaboration)

Corporations' self-financed R&D funds in FY2008 totaled ¥14.5 trillion, of which funds paid outside, such as universities and other corporations, amounted to ¥2.2 trillion

The number of joint research and business-funded research projects conducted by public and private universities has been increasing since FY2001. They have also increased in terms of value.[7]

Figure 10 shows that the number of university ventures that were engaged in business activity as of the end of FY2008 was 1,809. The number of university ventures began to decrease in around FY2005 after increasing sharply in the preceding 10 years or so.

(Issues and Efforts Concerning Innovation System)

Figure 11 shows that in joint research and funded research projects with corporations, the areas of activities focused on by universities began to change in FY2003 through FY2008. The areas of activities focused on by universities in FY2008 were "matching industry-academia needs and seeds" and "identification of needs in companies."

Recently, there are growing moves to promote R&D by forming a network of experts of organizations in various fields, by creating an innovation platform (intellectual platform) that produces new methodology or breakthrough and by studying strategies through collaboration of industry, government and academia (R&D-type independent administrative institutions, etc.). (Example; "Tsukuba Innovation Arena," a global research center for nanotechnology innovation).

Also, the formation of information networks, like J-GLOBAL, is expected to promote new collaboration among industry, government and academia and among corporations in different fields, as such networks make information easily available to anyone. J-GLOBAL (in operation since FY2009; Japan Science and Technology Agency) is a new service that supports knowledge and unexpected discoveries in different fields by mutually linking basic information concerning research and development (researchers, universities and public research institutions, research papers, patents, research projects, and scientific and technical terms, etc.).

② New systems concerning R&D institution

R&D institutions are major research and development implementation institutions along with private-sector corporations and universities. There are 38 R&D institutions (as of April 2010) defined under the "Research and Development Enhancement Act" that went into effect in 2008.

Relevant ministries are now studying appropriate measures for the system of R&D institutions from the perspective of the particularity of research and development, securing excellent human resources and ensuring international competitiveness. They are expected to adopt necessary measures by October 2011. An interim report[8] proposed the establishment of a "Organization of National Institute of Research and Development (tentative)," management reform through promotion of flexible use of budget in accordance with R&D characteristics and inter-ministry efforts, and governance reform through implementation of evaluations from a global standpoint.

2-3 Main Points of "Chapter 3: Science and Technology with Society and People"

Chapter 3 discusses the importance of people's understanding of and participation in science and technology in order to further develop the science and technology described in Chapter 1 and Chapter 2.

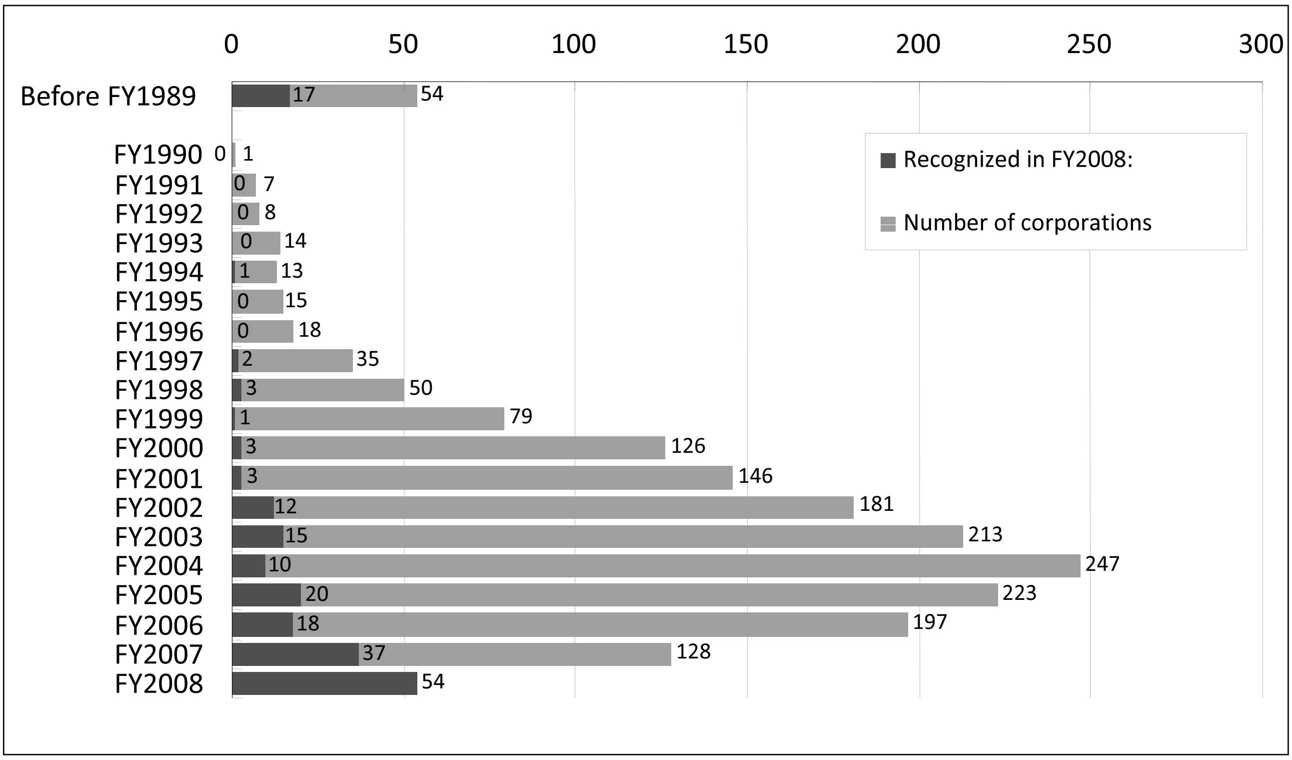


Figure 10 : Trends in the number of university ventures founded each year

Source: FY2008 survey commissioned by the Ministry of Economy, Trade and Industry, "Basic Survey on University Ventures," Japan Economic Research Institute

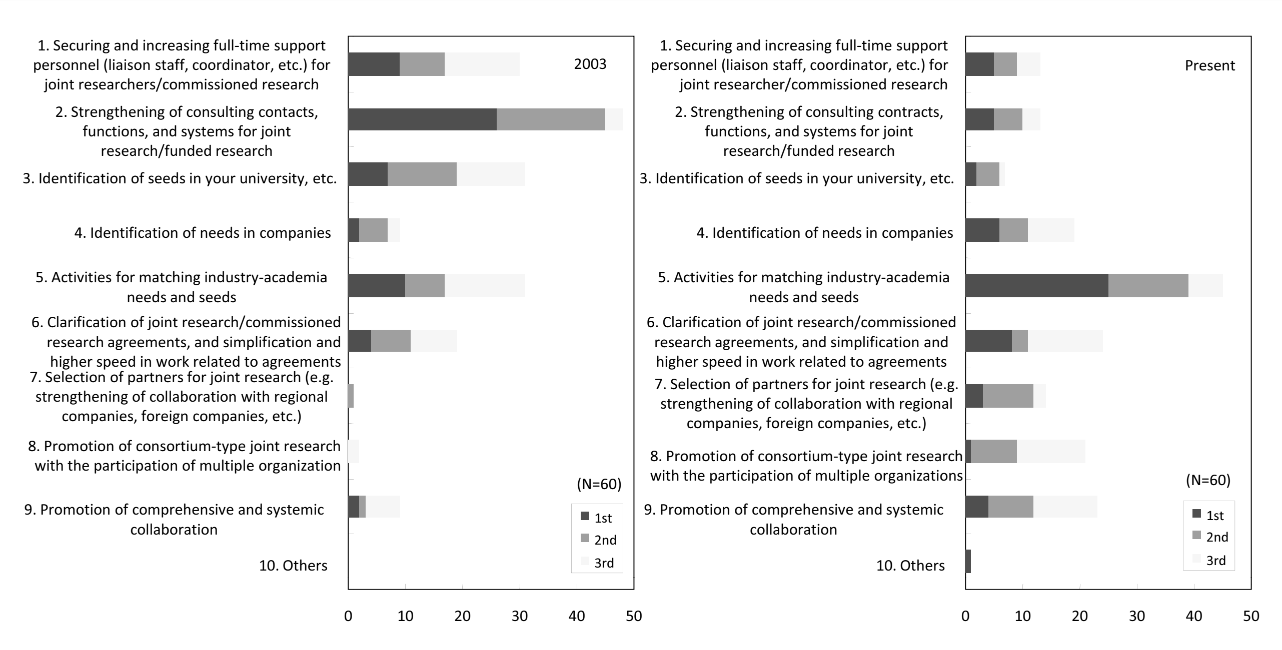


Figure 11 : Changes in the activities focused on by universities in joint and subcontracted research

Source: "Analysis of the Innovation Systems: Part1, Creation and industry-academia-government collaboration and intellectual properties" (2009), NISTEP

Amid deepening relationship between science/technology and society and growing calls for reflecting public opinions on policies and research, activities to promote dialogue between researchers and the people have increased. After the change of government, new efforts are being made to make the budget-making process focused and efficient and to secure transparency of the policy-making process.

(1) Enhancing of understanding and sympathy for science and technology

The 3rd Science and Technology Basic Plan calls for promoting outreach activity (interactive communication activity between researchers and people to have the researchers share people's needs through dialogue). In recent years, many outreach activities have come to be performed. In order to promote outreach activity, it is hoped that universities will make systematic efforts to develop and secure expert human resources.

Science and natural history museums have played a central role in S&T communication activities by offering easy-to-understand answer books on science and technology, displaying samples, holding lecture meetings and events, and offering hands-on learning experience. It is hoped that they will continue to develop human resources engaged in such activities and support volunteer activities.

(2) New developments in S&T policy

(Growing argument concerning science and technology)

In November 2009, the Government Revitalization Unit examined government operations, including those in the area of science and technology, and after screening processes, handed down verdicts, including reviewing some of the government operations and budget cutbacks. The verdicts caused repercussions in various circles, including academic societies. In order to reflect the voice of the people in budget making, the MEXT solicited public opinions on the projects subjected to the screening process (Nov. 16~Dec. 15, 2009) and received about 20,000 opinions.

As described above, after the change of government, the new government has been promoting S&T policy more effectively and efficiently, while reviewing the way to promote science and technology and promoting transparency through new efforts, such as seeking public comments in determining the priority of government projects.

(New developments in S&T policy)

The Council for Science and Technology Special Committee on the Science and Technology Basic Plan inof MEXT has positioned Japan's future S&T policy as one of the main "social and public policies" to link S&T knowledge to the creation of new value for the realization of affluent national life and human society in response to requests from society and the people, instead of simply limiting its purpose to the promotion of science and technology. Moreover, from the standpoint of promoting efforts to solve the important policy issues that have been set based on social needs, etc., the committee maintains that it is essential to shift to an integrated policy combining S&T policy and other policies related to S&T innovation.[9]

Other countries place emphasis on comprehensive policies covering even measures to create innovation (science, technology and innovation policies) and therefore have been promoting the development of indexes and evaluation methods and the systematic improvement of statistics to that end.

3 Conclusion

Recently, science and technology have come to be globally viewed as important in ensuring a country's economic growth and affluent national life, and the importance of S&T policy has increased along with it. It is expected that S&T policy will become S&T/innovation policy and show new developments under a new framework.

Incidentally, since the White Paper on Science and Technology 2010 is the first white paper prepared by the new government that came into power in September 2009, it also touches on recent trends in S&T policies implemented by the new government (such as the screening of government projects by the Government Rehabilitation Unit and the creation of new systems concerning research and technology corporations) and the future outlook of science and technology policy.

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[6] WIPO Statistics Database, December 2009, Patent applications by patent office and country of origin (1995-2008)

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Profile

Yuko ITO
Senior Specialist, Research and Coordination Division, Science and Technology Policy Bureau, MEXT http://www.mext.go.jp
Senior fellow, NISTEP. Ph.D. in Pharmaceutical sciences.

Her main research themes are "research survey concerning passing the results of research on life science onto society" and "analysis of factors affecting the development process of basic research." Since July 2009, she has been on loan to the Research and Coordination Division, Science and Technology Policy Bureau, Ministry of Education, Culture, Sports, Science and Technology.

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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).

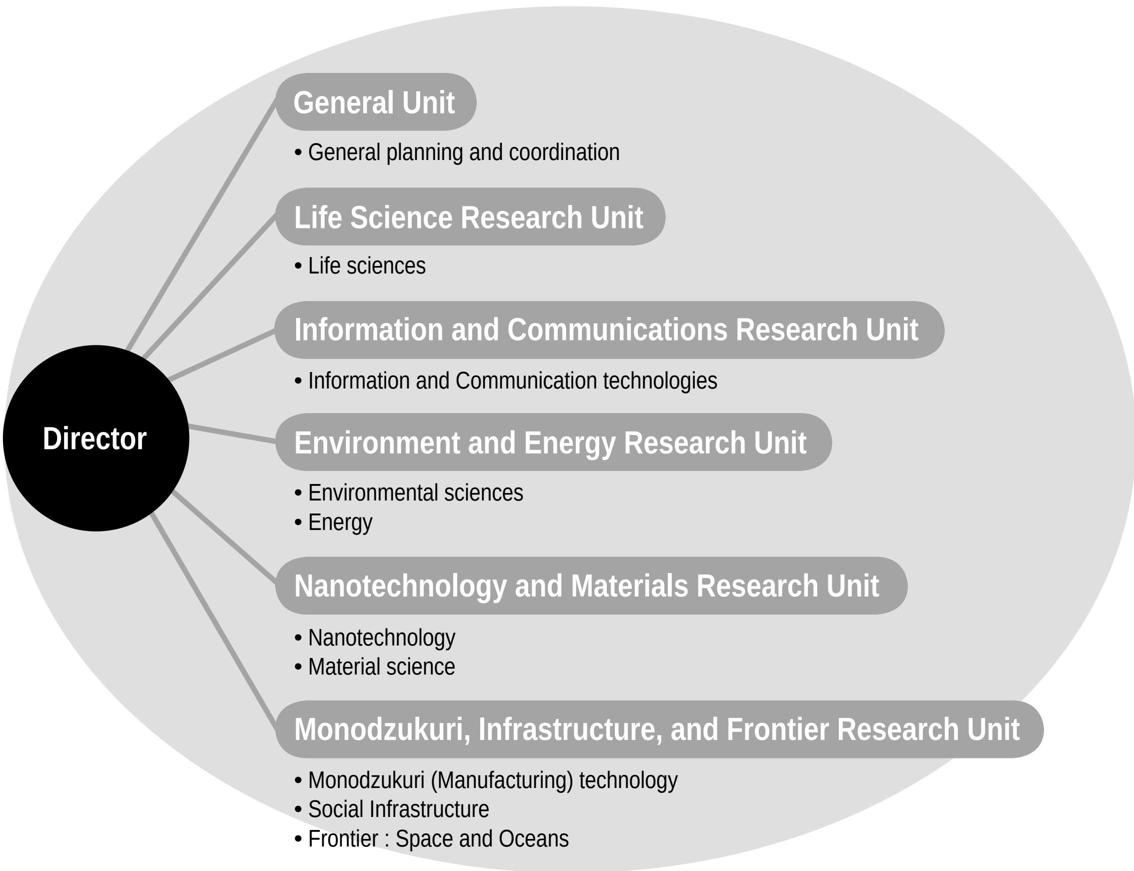
3. S&T foresight and benchmarking

— 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